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Living Evidence Synthesis 15.2: Effectiveness of Ventilation, Air Filtration and Disinfection for reducing transmission of Respiratory Infectious Diseases in non-health care community-based settings.

Date of Literature Search: 28 March 2024

This living evidence synthesis (LES) is part of a suite of LESs of the best-available evidence about the effectiveness of public health and social measures (PHSMs) (quarantine and isolation, masks, ventilation, physical distancing and reduction of contacts, hand hygiene and respiratory etiquette, cleaning, and disinfecting), as well as combinations of and adherence to these measures, in preventing transmission of respiratory infectious diseases. This is the 2nd version of this LES, which includes enhancements in scope from the first version by: 1) expanding the primary outcomes from COVID-19 transmission to include other prioritized respiratory infectious diseases (Influenza, Measles, Respiratory Syncytial Virus); and 2) expanded searches to include these outcomes and to search to further back in time. The next update to this and other LESs in the series is to be determined, but the most up-to-date versions in the suite are available here. We provide context for synthesizing evidence about public health and social measures in Box 1.

Suggested citation: Velásquez-Salazar P, Villatoro-Rodríguez SN, Garcia D, Ramirez CL, Rodriguez C, Patiño-Lugo DF, Florez ID. Living Evidence Synthesis 15.2: Effectiveness of Ventilation, Air Filtration and Disinfection for reducing transmission of respiratory infections in non-health care community-based settings. Unit of Evidence and Deliberation for Decision Making (UNED), University of Antioquia, 28 March 2024.

Questions

Q1: What is the effectiveness of improving ventilation, air filtration, and disinfection (VAFD) measures on reducing the transmission of respiratory infectious diseases (RIDs), and concentration of infectious particles in the air, in community-based settings (i.e., not clinical or healthcare settings), including SARS-CoV-2, influenza, RSV, and measles?

Secondary Scoping Question(s):

- Q1.1:What is the effectiveness of **different numbers of air changes per hour (ACH)** for optimal ventilation to minimize transmission of RIDs in community-based settings?
- Q1.2:What is the effectiveness of **different ventilation and air conditioning (HVAC) systems** (e.g. displacement, mixing systems) to reduce transmission of RIDs?
- Q1.3: What is the effectiveness of **different filters and filter ratings** to use in a mechanical ventilation (MV) system to reduce transmission of RIDs in community-based settings?
- Q1.4: What is the effectiveness of **portable air cleaners (PAC)** in reducing transmission of RIDs in community-based settings?

- Q1.5: What is the effectiveness of **different environmental conditions** (e.g. temperature and humidity) to target for optimal ventilation to reduce transmission of RIDs in community-based settings?
- Q1.6: What is the effectiveness of **different building/room designs** (e.g. number and position of mechanical air supplies, exhausts, windows, and doors) **and ventilation types in building designs** (e.g. cross ventilation, single-sided ventilation) for airflow to reduce transmission of RIDs?
- Q1.7: What is the effectiveness of **different combinations of ventilation and filtration strategies** in reducing transmission of RIDs in community-based settings?

Executive summary

Background

- Airborne transmission occurs when virus-laden respiratory particles, released by infected individuals, travel with air flow patterns instead of following their own trajectory. Inhalation of these particles by others may lead to infection, influenced by factors like viral load and individual characteristics. Ventilation rates and airflow patterns affect particle routes and distances, making airborne transmission a recognized route of SARS-CoV-2 transmission (1).
- SARS-CoV-2 shares airborne transmission traits with influenza, measles, and respiratory syncytial viruses (RSV) (2). Influenza A and B viruses cause seasonal epidemics, while avian influenza sporadically infects humans (3). Measles is highly contagious, with the virus remaining airborne for up to two hours (4). RSV mainly affects children, causing yearly outbreaks and infant hospitalizations (5).
- Heating, ventilation and air conditioning (HVAC) systems within the built environment can increase or mitigate the risk of airborne transmission of particles. Several principles regarding ventilation are well-established and supported by organizations that set standards for the HVAC industry such as the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).
- ASHRAE sets standards for testing and application of HVAC features that guide practices in North America. A statement from ASHRAE in April 2021 acknowledged that airborne transmission of SARS-CoV-2 is significant and provided guidance on changes to building operations including HVAC systems (6). In July 2023, ASHRAE's Standard 241 was released. This standard aims to establish minimum requirements reducing the risk of disease transmission in buildings and exposure to pathogens, including SARS-CoV-2 and influenza viruses (7).
- ASHRAE (8) and the United States Environmental Protection Agency (9) (EPA) recommend using portable air cleaners when existing HVAC systems don't meet ASHRAE standards. These devices use one or a combination of technologies (e.g., filters, ultraviolet light in the germicidal wavelengths [UV-C]) to remove particles and kill infectious agents (10). However, ASHRAE advises that portable air cleaners using some technologies such as ionizers and photocatalytic oxidation [UV-PCO]) are considered emerging without proven efficacy and may convert contaminants to other potentially harmful compounds (10).

Profile of included studies

- Through searches, 4,151 articles were identified, from which 77 studies were included that addressed question 1.1 (n=35), question 1.2 (n=24), question 1.3 (n=10), question 1.4 (n=6), question 1.5 (n=7), question 1.6 (n=9), and/or question 1.7 (n=15), and:
- Searches were conducted to include the period from January 1st 2020, to March 28th, 2024. Most of the included studies were published between 2021-2022 (n=57).
- COVID-19 was the most studied disease (n=72), followed by Influenza and Influenza-like illness (n=4), and measles (n=1) (no studies addressed RSV).
- Study designs included modelling (n=61), cross-sectional (n=7), quasi-experimental (n=1), cohort (n=5), case-control (n=2), and a cross-over Randomized Controlled Trial (RCT) (n=1).
    - Studies were commonly conducted in the U.S. (n=16), China (n=11), and Germany (n=8).
    - In addition, studies reported on the RIDs transmission outcome (n=69); effectiveness at reducing the concentration of infectious particles in the air outcome (n=7); and PAC unintended consequences (n=1).

Key points in relation to question 1.1 Effectiveness of <u>improving ACH</u> in community settings

- In community settings, 29 studies reported on SARS-CoV-2 transmission reduction outcome:
    - 9/10 studies (settings: educational n=2, transport vehicles and hubs n=4, retail n=1, other indoor settings n=2) reported a benefit of increasing ACH.
    - 14/16 studies (settings: educational n=2, transport vehicles and hubs n=4, retail n=1, residential n=1, workplace n=1, other indoor settings n=5) found a benefit from increasing ventilation rates (VR).
- 6/6 studies (settings: industrial n=1, retail n=1, workplace n=1, other indoor settings n=3) reported a benefit of increasing outdoor air (OA) strategies.
- In community settings three studies reported on the reduction of SARS-CoV-2 concentration in air outcome:
    - 2/2 studies (residential n=1, indoor settings n=1) reported the effectiveness of increasing ACH
    - One study found a benefit of increasing OA in workplace settings
    - One study found a benefit from increasing VR in educational settings
- Two studies reported on influenza transmission reduction outcome, one case-control study in educational settings, and one modelling study in non-specified indoor settings.
    - 2/2 studies reported that increasing ventilation rates reduced influenza risk.
- One modelling study in educational settings reported on measles transmission reduction outcome and found that increasing ventilation rates reduced measles risk.
- No studies were found through this search that reported on measles or influenza viral concentration reduction in air, or on RSV transmission or viral concentration reduction in air.
- Quality of non-modelling studies: two cohort studies both with critical RoB, one cross-sectional study with serious RoB and one case-control study with moderate risk.

Key points in relation to question 1.2 Effectiveness of different types of <u>Heating Ventilation and Air Conditioning (HVAC) systems</u> in community settings

- In community settings, 22 studies reported on SARS-CoV-2 transmission reduction outcome in the following settings: educational (n=6), industrial settings (n=2), residential (n=2), retail (n=1), transport vehicles (n=6), workplace (n=1) and non-specified indoor setting (n=4). Of these studies:
  - 2/2 studies found no significant differences between having or not having a ventilation system in industrial settings.
- When comparing mechanical ventilation (MV) with natural ventilation (NV) in indoor settings, one study found greater benefit with MV and one with NV. Mixed ventilation was superior to MV in one study. In transport vehicles, natural and mixed ventilation types were superior to MV.
  - 4/4 studies (educational settings n=3, residential settings n= 1) found greater benefit by increasing NV practices such as opening windows/doors or increasing periods in which windows are left open. One study (educational setting) reported a benefit by increasing NV in response to CO2 sensors.
  - Three studies (transport vehicles or hubs n=1, unspecified indoor settings n=2) compared mixed ventilation systems with displacement ventilation (DV). One study found the DV system superior, while another found the mixed ventilation system superior, and in one study carried out within vehicles, the benefit varied depending on the passenger's position.
  - 6/6 studies (settings: retail n=1, workplace n=1, educational n=2 and transport vehicles and hubs n=2)) favoured rebalancing HVAC systems to increase airflow or air velocity.
- One study in residential settings reported that implementation of a balanced constant airflow ventilation system (BV) was superior to exhaust-only ventilation (EV), which was in turn superior to the humidity-based demand-controlled ventilation system (RH-DCV).
- One modelling study (unspecified indoor setting) found a smart ventilation control strategy based on occupant-density detection superior to traditional fixed ventilation.
- One study reported that mixed mode ventilation was superior to front mode, MV alone or windshield defrosting mode in transport vehicles.
- One study reported that complete mixed mode was superior to incomplete mixed mode, and partition of zones within complete mixed ventilation was beneficial in unspecified indoor settings.
- In community settings two studies reported on the reduction of SARS-CoV-2 concentration in air outcome:
  - One study found greater benefit by opening the windows than by not opening them in residential settings.
  - One study reported a significant benefit of increasing the inlet velocity in workplaces.
- One modelling study assessed influenza transmission reduction outcome in educational settings and reported a benefit from adjusting window opening and closing periods based on real-time monitoring of indoor CO2 concentration.
- No studies were found through this search that report on measles or influenza viral concentration reduction in air, or on RSV transmission reduction or viral concentration reduction in air.
- Quality of non-modelling studies: three cohort studies, two with critical RoB and one with moderate risk, four cross-sectional studies, two with serious RoB and two with critical risk; and a case-control study with low RoB.

Key points in relation to question 1.3 Effectiveness of different filters and filter ratings in community settings

- Eight modelling studies reported on SARS-CoV-2 transmission outcome in different settings: educational (n=2), transport vehicles or hubs (n=1), superspreading events (n=1), and non-specified indoor settings (n=4). Of these studies:
    - 7/7 (indoor settings n=3, transport vehicles or hubs n=1, educational n=2 and superspreading events n=1) reported a benefit of upgrading central HVAC filter efficiency
    - One study in unspecified indoor settings reported that the use of high-efficiency particulate air (HEPA) filtration systems also reduced SARS-CoV-2 transmission risk.
- Only one modelling study reported results on SARS-CoV-2 concentration reduction on air outcome. The study found a benefit of upgrading central HVAC filter efficiency in workplaces.
- One modelling study reported results on measles transmission outcome and found a benefit of upgrading central HVAC filter efficiency in educational settings.
- No studies were found through this search that report on measles viral concentration reduction in air, or on influenza/RSV transmission or viral concentration reduction in air
- Quality of evidence: all studies that evaluated the effectiveness of filters were carried out with modelling studies, so the RoB was not evaluated.

Key points in relation to question 1.4 Effectiveness of Portable Air Cleaners (PAC) in community settings

- Four studies reported on SARS-CoV-2 transmission outcome, including modelling designs (n=2), cohort (n=1) and crossover RCT (n=1). Studies were conducted in retail (n=1), residential (n=1) and non-specified specified indoor (n=2) settings.
- 3/4 studies (indoor n=2, retail n=1) reported a benefit of PAC interventions including the implementation of air purifiers and upper-room UVGI (n=1), increasing PACs capacity with HEPA (n=1), and personal ventilation (not specified) (n=1). One study found non-significant differences between having PACs with HEPA or not having them.
- Only one crossover RCT in residential settings reported results on SARS-CoV-2 concentration reduction on air outcome. The study did not find significant differences between HEPA and sham in PACs.
- One modelling study reported results on measles transmission outcome and found a benefit of doubling Clean Air Delivery Rates (CADR) of air purifiers in educational settings.
- No studies were found through this search that report on measles viral concentration reduction in air or on influenza/RSV transmission or viral concentration reduction in air
- Quality of evidence from non-modelling studies: one cohort study had critical RoB, one quasi-experimental study with moderate RoB and one cross-over RCT study with high RoB. bias.

Key points in relation to question 1.5 Environmental conditions in community settings

- Five modelling studies reported on SARS-CoV-2 transmission outcome. Studies were conducted in retail (n=1), educational (n=2) and non-specified indoor (n=2) settings.
    - Only 1/4 studies reported a benefit of higher relative humidity (RH) in unspecified indoor settings.

  - One study reported having a low-heat source in restaurants vs not having it increased infection risk.
- Only one modelling study addressed SARS-CoV-2 concentration reduction in air outcome. The study reported a benefit resulting from increasing inlet temperature in workplaces.
- Two studies evaluated influenza transmission in community settings:
  - One cohort study in unspecified indoor settings found a benefit of lower RH
  - One modelling study reported that having a heat source was superior to not having a heat source in children's bedrooms during night.
- No studies were found through this search that report on influenza viral concentration reduction in air, or on measles/RSV transmission or viral concentration reduction in air outcomes.
- Quality of evidence from non-modelling studies: one cohort study with critical RoB.

Key points in relation to question 1.6 Building/room designs in community settings

- Seven studies reported on SARS-CoV-2 transmission reduction outcome, including modelling (n=5) and cross-sectional designs (n=2). Studies were conducted in educational (n=2), residential (n=1), and other indoor settings (n=4).
  - 5/5 studies (settings: educational n=2, indoor n=2, residential n=1) found a beneficial effect of building openings optimization.
  - One study found a benefit of repositioning supply/exhaust diffusers to create directional airflow in indoor settings.
  - One study did not find significant associations between proximity of inlet/outlet and infection rate in indoor settings.
- Two modelling studies reported on SARS-CoV-2 concentration reduction in air outcome. Studies were conducted in workplaces and reported on multiple interventions in building/room designs.
  - One study reported that viral concentration reduction was associated with increased room size, opened windows everywhere except restrooms, and installing enhanced MV systems, while implementing office partitions was associated with increased viral concentrations.
  - The other study did not find significant associations between viral concentrations and repositioning supply/exhaust diffusers.
- No studies were found through this search that reported on influenza, measles or RSV transmission or viral concentration reduction in air outcomes.
- Quality of evidence from non-modelling studies: two cross-sectional studies, one with critical risk and the other with moderate RoB.

Key points in relation to question 1.7 Combination of VAFD strategies in community settings

- 14 studies reported on SARS-CoV-2 transmission reduction outcome, including modelling (n=13) and cross-sectional designs (n=1). Studies were conducted in educational (n=7), transport, vehicles or hubs (n=2), workplace (n=1), and other indoor settings (n=4).
- Combined interventions that were found to be effective for this outcome included: Ventilation + air filtration (n=1), Increase VR + Upgrade central HVAC filter efficiency (n=1), Upgrade

HVAC filters + HEPA filtration (n=1), Increase VR + CO2-based airing (n=1), Increase VR + Upgrade central HVAC filter efficiency (n=1), Increase ACH + Upgrade central HVAC filter efficiency (n=1), Increase OA + UVGI (n=1), PAC + Mitigation strategies (n=1), Opening windows, doors, or using fans + HEPA filtration with or without purification with UVG (n=1), NV+ MV (n=2), Optimization of Window Openings + Integration of Window-Integrated Fans (n=1), Opening windows + air conditioning (AC)/fans (n=1). Dilution Ventilation and Ventilative Cooling (DVVC) + Low Specific Fan Cooling (LSFP) effectiveness was found dependant on the occupation (n=1).

- One modelling study reporting on measles transmission reduction outcome in educational settings found benefits of the combination of VR +Upgrade central HVAC filter efficiency + Upgrade air purification
- No studies were found through this search that report on SARS-CoV-2/measles viral concentration reduction in air outcomes, or on influenza/RSV transmission or viral concentration reduction in air outcomes.
- Quality of evidence from non-modeling studies: one cohort study with critical RoB.

Overview of quality of evidence

Of the studies included in this review, only 16 were real-life studies, in which the tool for assessing RoB was applied according to the design of each study. The rest were simulation and/or modelling studies, in which RoB was not assessed. Of the 7 cross-sectional studies, one had low RoB, two had serious risk, and four had critical risk. Two studies were case-control studies, one of them had low risk and the other moderate risk. Five were cohort studies, one of them for one of the outcomes obtained a moderate risk and for a second outcome it had a critical risk, the other four studies had a critical RoB. Only one study had a quasi-experimental design and was assessed as having a moderate RoB. Only one of the studies was a clinical trial which had a high RoB.

Overview of evidence and knowledge gaps

Most of the evidence on the effectiveness of VAFD measures in reducing RID transmission comes from modelling studies. As this type of data only provides indirect evidence and its use in real world settings can be challenging, this type of evidence was not taken into account to identify the following knowledge gaps.

Knowledge gaps in the effectiveness of VAFD to reduce the transmission of RIDs

- Measles and RSV: There is a lack of direct evidence (i.e., from experimental and observational design studies) on the effectiveness of all VAFD strategies, specifically in community settings, to reduce the transmission of RSV and measles.
- Influenza: There is a lack of direct evidence of the effectiveness of filters for use in a MV system, filter ratings, environmental conditions, PAC, different building/room design and combinations of ventilation and filtration strategies, specifically in community settings, to reduce the transmission of influenza.
- SARS-CoV-2: There is a lack of direct evidence of the effectiveness of systems filter and filter ratings to use in a MV system and environmental conditions, specifically in community settings, in reducing the transmission of SARS-CoV-2.

Knowledge gaps in the effectiveness of VAFD to reduce the concentration of infectious particles in air

- Influenza, measles and RSV: There is a lack of direct evidence of the effectiveness of all VAFD strategies, specifically in community settings, in reducing the concentration of infectious particles of influenza, RSV, and measles.
- SARS-CoV-2: There is a lack of direct evidence of the effectiveness of systems filter and filter ratings to use in a MV system, environmental conditions, different building/room design and combinations of ventilation and filtration strategies, specifically in community settings, in reducing the concentration of infectious particles of SARS-CoV-2.

Box 1: Context for synthesizing evidence about public health and social measures (PHSMs)

This series of living evidence syntheses was commissioned to understand the effects of PHSMs during a global pandemic to inform current and future use of PHSMs for preventing transmission of respiratory infectious diseases.

General considerations for identifying, appraising and synthesizing evidence about PHSMs

- PHSMs are population-level interventions and typically evaluated in observational studies.
  - Many PHSMs are interventions implemented at a population level, rather than at the level of individuals or clusters of individuals such as in clinical interventions.
  - Since it is typically not feasible and/or ethical to randomly allocate entire populations to different interventions, the effects of PHSMs are commonly evaluated using observational study designs that evaluate PHSMs in real-word settings.
  - As a result, a lack of evidence from randomized controlled trials (RCTs) does not necessarily mean the available evidence in this series of LESs is weak.
- Instruments for appraising the risk of bias in observational studies have been developed; however, rigorously tested and validated instruments are only available for clinical interventions.
  - Such instruments generally indicate that a study has less risk of bias when it was possible to directly assess outcomes and control for potential confounders for individual study participants.
  - Studies assessing PHSMs at the population level are not able to provide such assessments for all relevant individual-level variables that could affect outcomes, and therefore cannot be classified as low risk of bias.
- Given feasibility considerations related to synthesizing evidence in a timely manner to inform decision-making for PHSMs during a global pandemic, highly focused research questions and inclusion criteria for literature searches were required.
  - As a result, we acknowledge that this series of living evidence syntheses – about the effectiveness of specific PHSMs (i.e., quarantine and isolation; mask use, including unintended consequences; ventilation, reduction of contacts, physical distancing, hand hygiene and cleaning and disinfecting measures), interventions that promote adherence to PHSMs, and the effectiveness of combinations of PHSMs – does not incorporate all existing relevant evidence on PHSMs.
  - Ongoing work on this suite of products will allow us to broaden the scope of this review for a more comprehensive understanding of the effectiveness of PHSMs.
  - Decision-making with the best available evidence requires synthesizing findings from studies conducted in real-world settings (e.g., with people affected by misinformation, different levels of adherence to an intervention, different definitions and uses of the interventions, and in different stages of the pandemic, such as before and after availability of COVID-19 vaccines).

Our approach to presenting findings with an appraisal of risk of bias (ROB) of included studies

To ensure we used robust methods to identify, appraise and synthesize findings and to provide clear messages about the effects of different PHSMs, we:

- acknowledge that a lack of evidence from RCTs does not mean the evidence available is weak
- assessed included studies for ROB using the approach described in the methods box
- typically introduce the ROB assessments only once early in the document if they are consistent across sub-questions, sub-groups and outcomes, and provide insight about the reasons for the ROB assessment findings (e.g., confounding with other complementary PHSMs) and sources of additional insights (e.g., findings from LES 20 in this series that evaluates combinations of PHSMs)
- note where there are lower levels of ROB where appropriate
- note where it is likely that risk of bias (e.g., confounding variables) may reduce the strength of association with a PHSM and an outcome from the included studies
- identify when little evidence was found and when it was likely due to literature search criteria that prioritized RCTs over observational studies.

Implications for synthesizing evidence about PHSMs

Despite the ROB for studies conducted at the population level that are identified in studies in this LES and others in the series, they provide the best-available evidence about the effects of interventions in real life. Moreover, ROB (and GRADE, which was not used for this series of LESs) were designed for clinical programs, services and products, and there is an ongoing need to identify whether and how such assessments and the communication of such assessments, need to be adjusted for public-health programs, services and measures and for health-system arrangements.

Findings

Overall, the search identified 4,151 records. 3,856 were screened in title/abstract, 712 in full text, and 77 studies were considered for this summary. The reasons for excluding the remaining 635 studies are reported in the second section of Appendix 2. Figure 1 presents the PRISMA flow diagram.

Highlights of changes in this report

- Scope has been expanded to include respiratory syncytial virus (RSV), measles and influenza.
- Primary question has been divided into sub questions that are further divided by ventilation, air filtration, and disinfection (VAFD) strategies.
- A secondary outcome that reports on reducing concentration of infectious particles in the air has been included.
- Table 5 on unintended consequences of VAFD was not updated in this version of the report.
- 62 new studies (highlighted in yellow) have been added since the previous edition of this living evidence synthesis, last updated 28 Mar 2023. The newly added studies include results for SARS-CoV-2 (n=58), Influenza (n=2), measles (n=1), and the three of them (n=1).

Effectiveness of different numbers of air changes per hour (ACH) for optimal ventilation in community-based settings

Overall, 35 studies (11–46) that addressed ACH interventions in community settings were found (educational=11; transport, vehicles and hubs=6; retail=3; residential=2; workplaces=3; courtroom=1; industrial=1; superspreading events=1; and other non-specified indoor settings=7). Most of the studies were modelling designs (n=31),

Box 2: Our approach

We retrieved studies by searching: 1) PubMed; 2) Science Direct; and 3) CINAHL. Searches were conducted for studies reported in English, conducted with humans and published since 1 January 2020. Detailed search strategy is included in **Appendix 1**, and eligibility criteria in **Appendix 2**.

Studies identified up to March 28th, 2024 that reported on empirical data with a comparator were considered for inclusion. Studies excluded based on full text review are provided in **Appendix 3**.

Population of interest: All population groups that report data related to COVID-19, RSV, measles and influenza.

Intervention and control/comparator: Different rates and mechanisms (i.e., mechanical, natural, or infiltration) of air dilution; different filter ratings; and different combinations of ventilation and filtration strategies. Definitions provided in **Appendix 4**.

Effectiveness outcomes:
Primary outcome: Reduction in transmission of SARS-CoV-2, RSV, measles and influenza.
Secondary outcomes: Reduction in air concentration of microorganisms.

Study selection: One reviewer screened all titles and abstracts; a second reviewer screened those that were excluded by the first reviewer to ensure no potentially relevant records were missed. The full text of potentially relevant studies was reviewed by one reviewer. All team members discussed those that were unclear.

Data extraction: Data extraction was conducted by one team member and checked for accuracy and consistency by another using the template provided in **Appendix 5**.

Critical appraisal: Risk of Bias (ROB) of individual studies was assessed using validated ROB tools (by outcome). For cohort studies, we used a revised ROBINS-I tool and other observational designs we used JBI tools. Judgements for the domains within these tools were decided by consensus between at least two team members. Modelling studies were not assessed for ROB, as these are considered to provide indirect evidence of effects. Our detailed approach to critical appraisal is provided in **Appendix 6**.

Summaries: We synthesized the evidence by presenting a narrative summary of each study's findings. The next update to this document is to be determined.

followed by cohort (n=2), cross-sectional (n=1), and case control (n=1). SARS-CoV-2 was the most reported viral infection (n=33), followed by influenza (n=2) and measles (n=1). No studies were found that evaluated RSV. Transmission reduction/infection outcome (Primary outcome) was the most frequently assessed (n=31) , while viral concentration on air was assessed in four studies. The risk of bias (RoB) from studies was critical in the two cohort studies, high in the cross-sectional study and moderate in the case-control study.

The characteristics, findings and assessment of RoB of each study that assessed the primary outcome are presented in Table 1 for primary studies, and in Table 2 for modelling studies. The characteristics, findings and assessment of risk of each study that assessed the secondary outcome are presented in Table 3 for primary studies and in Table 4 for modelling studies.

SARS-CoV-2 transmission and infection risk

In community settings, 29 studies reported on SARS-CoV-2 transmission reduction outcome (12–40).

Increasing ACH: In transport vehicles or hubs, four studies addressed these interventions. In coach buses, open windows significantly improved natural ventilation (NV), with front and rear windows providing sufficient airflow. Wind catchers notably enhanced ventilation, reducing infection risk. At 90 km/h, ACH reached 448.86, compared to 146.07 at 30 km/h, highlighting vehicle speed's impact on ventilation and infection risk. Results emphasize the importance of window configurations and wind catchers in mitigating infection risk in coach buses (25). On railway coaches, one modelling study found that higher outdoor airflow rates reduced infection risk, with heat recovery maintaining lower risk and possibly improving energy efficiency. Infection risk probability decreased significantly with increased ventilation rates, particularly with masks, highlighting the efficacy of improved ventilation in reducing SARS-CoV-2 transmission on trains (16). In a modelling study, increasing ventilation in urban public transport systems, particularly by opening windows, significantly reduced infection transmission risks, notably in buses. However, ventilation alone might not prevent severe transmission events. Wearing masks, especially for both index cases and susceptible individuals, reduces infection risks (21). In transport, vehicles and hubs, factors like disease prevalence, passenger density, ventilation, and mitigation measures influence exposure in subway carriages. Higher ACH rates correspond to lower total virus doses received by passengers, highlighting the importance of improved ventilation in reducing transmission (40).

In commercial indoor spaces improving ventilation to 12 ACH resulted in significant cost savings and quality-adjusted life years (QALYs) gained (38).

In educational settings, one modelling study assessed ventilation and mitigation measures' impact on SARS-CoV-2 spread in a school for individuals with intellectual and developmental disabilities. It analyzed CO_2 levels, evaluated interventions, and estimated room airflow. However, it found no significant correlation between ventilation rates and SARS-CoV-2 cases (39). Simulating classroom scenarios, they found that increasing ventilation rates from 0.5 to 6 ACH reduced infection risk by up to 54% for particles smaller than 5 µm at constant RH. Ventilation emerged as the primary method for removing small infectious particles suspended in the air (14). In a retrospective cohort study in schools (total 10,441 classrooms, 1,419 schools) in Italy, the authors found that higher ventilation rates resulted in greater relative risk reduction and concluded that ACH >5 per hour ensures higher protection from respiratory infectious agents (Critical RoB) (17).

In indoor settings like offices, bars, and weddings, increasing ACH, outside air fraction (FOA), and filter efficiency consistently reduced infection risk, with mechanical filtration using filters with Minimum Efficiency Reporting Value (MERV) number 8 MERV 8 filters) notably effective. Increasing ACH was the most impactful measure, significantly reducing infections across scenarios. For instance, in offices, raising ACH from 2 to 6 resulted in a 28% infection reduction, emphasizing its efficacy (19). In other indoor settings increasing ventilation rates reduced infection risk by ~40%, with an 85% decrease in long-range airborne transmission contribution (22).

Increasing ventilation rates: 15/17 studies found a benefit of this intervention. One modelling study that investigated an October 2020 outbreak in a courtroom in Hamburg showed that probability of infection was lower with higher ventilation rates when the duration of the event was 1.5 and 3 hours but not at 0.5 hours; however, other factors influence transmission, specifically duration of exposure and emission rate from the infected source (index case) (35). Another model reported that aerosol exposure index for individuals sitting at different tables in a restaurant was lower with increased ventilation (24). In office settings, increasing air change rates significantly reduced aerosol transmission risk, especially when combined with efficient mask use (26). A study by Li et al conducted simulation experiments based on dormitory buildings in two provinces in China where outbreaks occurred in January to February 2020. Results did not consistently show lower infection rates with higher ventilation rates. Authors attributed differences in infection rates to mask wearing habits (23).

In educational settings, all studies (5/5) favored increasing ventilation rates to reduce SARS-CoV-2 transmission / infection risk. A modelling study that tested varying classroom volumes and ventilation rates, reported that increasing ventilation rates led to decreased simultaneous infections, indicating ventilation's effectiveness in reducing SARS-CoV-2 transmission, although the impact varied across different ventilation levels (34). In a university building, it was reported that as the air exchange rate (AER) increases, SARS-CoV-2 transmission decreases exponentially, but energy consumption rises. An AER of 2.8 hr^{-1} was identified as the balance point where infection risk and energy consumption meet (27). Another modelling study found a linear relationship between ventilation rate and infection risk. Additionally, ventilation rate significantly influenced both infection risks and building energy usage (36). In U.S. schools (over 111,000 schools), doubling ventilation rates was moderately effective in lowering infection risk but less impactful than MERV-13 filters. While comparable to hybrid learning, ventilation alone may not sufficiently reduce infection risk in all scenarios (12). High ventilation rates, facilitated by innovative systems like HEAHU, validated in Italian schools, reduces contaminants and contagion risk, achieving R0 below 1. Simulation demonstrates that MV decreases R0, with filtration efficiencies of 50% and 75%, indicating substantial reduction in contagion risk even at lower ventilation rates (32).

During superspreading events using an agent-based model, increasing horizontal air change rates elevates transmission risk, outweighing benefits of air filtration. Logit scale estimates show air change rate's positive association with transmission risk and filtration rate's negative association. Authors concluded that there is potential for ventilation airflow to expose susceptible people to aerosolized pathogens even if they are relatively far from infectious individuals, and maximizing the vertical aerosol removal rate is paramount to successful transmission-risk reduction (20).

In transport vehicles and hubs, factors like disease prevalence, passenger density, ventilation, and mitigation measures influence exposure in subway carriages. Higher ventilation rates correspond to lower total virus doses received by passengers, highlighting the importance of improved ventilation in reducing transmission (40). Higher heating, ventilation and air conditioning (HVAC) flow rates correlated with reduced inhaled viral doses and lower SARS-CoV-2 Delta variant infection risks in car cabins. At 100% flow rate, infection risk ranged from 0.76% to 35% (15). One modelling study during an outbreak caused by the same infected individual on two buses estimated ventilation rates in each bus and found that attack rate (number of infected cases/number of persons) was higher on the bus with the lower ventilation rate (15.2% vs. 11.8%) (28).

In other indoor scenarios, modelling studies reported that increasing ventilation rates from 0.5 to 6 h^{-1} significantly decrease infection risk for all viruses (13). In multiroom buildings via air handling systems, higher air change rates reduce infection probability in source rooms but increase spread to connected rooms (30). Doubling total supply airflow rates also shows significant risk reduction, averaging around 37% in different indoor scenarios (33).

Increasing outdoor air (OA): All the studies (6/6) reported a benefit of this intervention. One cross-sectional study in meat and chicken processing plants assessed OA flow per employee in a working area = outdoor air flow / (number of employees in a working area / number of shifts in the working area). Overall results of multivariable logistic regression for maximum outdoor air flow (OAF) per employee found no significant difference [aOR, 1.000 (95% CI 1.000–1.000)]. However, when the delivery, stunning/slinging/hanging, and slaughter areas were excluded from analysis (these areas have a process related high ventilation rate) (n=2,334) the association was significant [aOR, 0.996, (95% CI 0.993–0.999; including interaction term for temperature and OAF, [aOR, 0.984, (95% CI 0.971–0.996)] (Critical RoB) (31).

In retail settings, Clements et al. (2023) evaluated interventions to reduce SARS-CoV-2 transmission risk in enclosed spaces using a simulation model. High-ventilation interventions in a restaurant outbreak scenario significantly reduced the attack rate compared to baseline conditions with low ventilation. Adding medium-high ventilation and reducing occupancy further decreased the median risk of transmission, even when combined with surgical masks. However, masks alone did not sufficiently lower the risk from a superspreader (18).

One modelling study in office buildings found that increasing outdoor airflow significantly reduces infection risk across climates. Adjusting OA fraction from 30% to 100% consistently lowers infection risk (29).

In other indoor settings, three modelling studies favored OA increasing. One study reported that across various indoor settings, increasing OA intake can notably reduce infection risk, with a 27% average reduction when using 100% OA. Doubling total supply airflow rates also shows significant risk reduction, averaging around 37% (33). In multizone mechanically ventilated buildings, when the OA percentage was adopted as 100%, the exposure risk was reduced to 1.12%, 40% down from the baseline case (37), and increasing OA fraction from 0% to 33% decreases infection risk from 0.22%

to 0.16%. In multiroom buildings via air handling systems, increasing OA fraction from 0% to 33% decreases infection risk from 0.22% to 0.16%. (30).

SARS-CoV-2 viral concentration in air
In community settings four studies reported on the reduction of SARS-CoV-2 concentration in air outcome (41–45), including one cohort study and three modelling studies:

Increasing ACH: In isolation dorm rooms housing at the University of Oregon, a significant decrease in aerosol sample positivity was not observed with increased ACH ($P = 0.43$). Despite increased ventilation reducing detectable viral load, the study suggests that the modest range of ACH values tested may not be adequate to reduce viral particles to undetectable levels in enclosed spaces (Moderate RoB) (42). A modelling study in indoor settings reported that breathing and coughing emitted thousands to millions of virus copies per cubic meter, with higher concentrations in smaller, less ventilated spaces. The viral load plateaued after 30 minutes in hospital ventilation (10 air exchanges per hour) but continued to rise in offices (3 air exchanges per hour) for over an hour. Superspreaders posed higher infection risks, emphasizing the need for respiratory protection in close, poorly ventilated environments (44).

Increase ventilation rates (VR): Ventilation adjustments in classrooms show significant reductions in Relative Exposure Index (REI), with 1.2 l s^{-1} per person yielding a high REI of 2.33, while 15.7 l s^{-1} per person decreases it to 0.38. Reduced airflow rates in high-emission spaces increase REI to 1.63 (43).

Increase OA: In an office building, supplying 100% OA significantly lowers virus concentration compared to MERV-10 filtration, especially on hot summer days, with reductions of up to 22%. The approach also decreases virus transmission potential (R0) by up to 0.20 (45).

Influenza transmission and infection risk
Two studies (13,46) reported on influenza transmission reduction outcome, one case-control study in educational settings, and one modelling study in non-specified indoor settings.

Increase VR: A two-phase study (phase I cross-sectional study and phase II case-control study) in Tianjin University dormitories, found that lower ventilation rates per person were associated with increased common cold and influenza infections among students during both summer and winter. In summer, high ventilation rates reduced influenza infections significantly. Additionally, poor ventilation combined with dampness increased the odds of influenza infections. Visible mold spots, damp stains, and water damage were associated with higher incidence of respiratory infections (46). In a modelling study about indoor settings, increasing ventilation rates from 0.5 to 6 h^{-1} significantly decreased infection risk for all viruses (13).

Measles transmission and infection risk
One modelling study in educational settings reported on measles transmission reduction outcome. The study found that increasing ventilation rates reduced measles risk. The authors reported that ventilation enhancements and air filtration reduce risk by 18-28% (11).

Effectiveness of different HVAC systems (e.g. displacement, mixing systems) in community-based settings

Overall, 24 studies (15,17,31,33,42,47–65) that addressed HVAC interventions in community settings were found (educational=6; transport, vehicles and hubs=6; retail=1; residential=3; workplaces=2; industrial=2; and other non-specified indoor settings=4). Most of the studies were modelling designs (n=16), followed by cross-sectional (n=4), cohort (n=3), and case control (n=1) . SARS-CoV-2 was the most reported viral infection (n=24), followed by influenza (n=1). No studies were found that evaluated measles or RSV. Transmission reduction/infection outcome was the most frequently assessed (n=22), while viral concentration in air was assessed in two studies. The RoB from non-modelling studies was critical in two of the cohort studies and moderate in one of them. In one of the cross-sectional studies the RoB was assessed serious, and three were assessed as critical RoB; in the case-control study the RoB was assessed low.

The characteristics, findings and assessment of RoB of each study that assessed the primary outcome are presented in Table 1 for primary studies, and in Table 2 for modelling studies. The characteristics, findings and assessment of risk of each study that assessed the secondary outcome are presented in Table 3 for primary studies and in Table 4 for modelling studies.

SARS-CoV-2 transmission and infection risk

22 studies (15,17,31,33,47–64) reported on SARS-CoV-2 transmission reduction outcome in different settings: educational (n=6), industrial settings (n=2), residential (n=2), retail (n=1), transport vehicles and hubs (n=6), workplace (n=1) and non-specified indoor setting (n=4). Of these studies:

Having vs not having an HVAC system: A cross-sectional study of 22 meat and chicken processing plants in Germany reported that based on results of multivariable logistic regression analysis (for subsample of companies with many infected workers), having a ventilation system reduced chance of testing positive for COVID-19. The results overall (6,522 workers) were not statistically significant [aOR, 0.757, (95% CI 0.563–1.018)]. Results by type of worker showed no significant association for regular workers [aOR, 1.076, (95% CI 0.619– 1.869)] but a significant reduction for temporary and contract workers [aOR, 0.541, (95% CI 0.368– 0.796)] (Critical RoB) (31). A concurrent case-control study (296 cases, 536 controls) at an oilfield worksite reported that adjusted odds ratios (aOR) showed no significant difference for ventilation at work [aOR, 0.68 (95% CI 0.36– 1.24)], office work [aOR, 0.93 (95% CI 0.53– 1.61)], or outdoor work [aOR, 0.75 (95% CI 0.43– 1.28)]. Authors concluded that individual factors (e.g., rare hand sanitizer use, social interactions outside of work) were main drivers of transmission, with little contribution by environmental factors (Moderate RoB) (54).

Natural ventilation (NV), mechanical ventilation (MV) or Mixed ventilation: A retrospective cohort study examined the impact of mechanical ventilation systems (MVS) installed in schools (total 10,441 classrooms, 1,419 schools) in Italy; the study period was September 2021 to January 2022. The incidence of COVID-19 cases (per 1,000 students) was 4.9 and 15.3 for schools with and without MVS, respectively; the incidence proportion ratio over the entire period studied was 0.32. Based on most conservative estimates (and controlling for mechanical ACH, compulsory schools, and number of students in the classroom), classrooms with MVS had a relative risk of 0.26 and relative risk reduction of 0.74; these estimates were statistically significant, but no confidence intervals were reported (Critical RoB) (17). In simulated indoor environments MV showed limited effectiveness, with stagnant air zones posing higher transmission risks. NV improved air circulation but had limitations like CO_2 accumulation. Ventilation type III (Mixed ventilation with optimization) exhibited the lowest risk. Despite improvements, no ventilation method alone fully mitigated transmission risks (59).

One modelling study assessed SARS-CoV-2 infection risks in various public transit microenvironments. Air Conditioned (AC) taxis posed the highest infection probability, while buses had a lower risk than both AC and non-AC taxis. Autorickshaws exhibited the lowest infection probability among studied modes. Estimates suggest an infection probability of 6.10×10^{-2} in AC taxis, 1.71×10^{-2} in non-AC taxis, 1.43×10^{-2} in buses, and 1.99×10^{-4} in autorickshaws. Such findings offer insights for mitigating transmission risks during commutes (61). In urban buses, HVAC off with closed windows showed low air mixing and potentially higher virus concentration. HVAC on with 100% recirculation dispersed exhaled gas but also increased virus inhalation risk. HVAC with 75% recirculation reduced maximum virus concentration by tenfold compared to 100% recirculation. Opening some windows resulted in the lowest virus concentration and negligible transmission risk, highlighting it as the safest option among scenarios studied (62).

NV: A retrospective cohort study on accommodation and household hygiene practices in 124 homes (335 people) with at least one case of laboratory confirmed COVID-19 in Beijing, China examined ventilation defined as the practice of opening the window to allow convection of indoor air and measured in hours per day. Though unadjusted analyses showed a significant association for ventilation [≤1 vs >1 hour/day OR, 2.55 (95% CI 1.14–5.70)], it was not significant in multivariable regression analyses. Authors concluded that the highest risk of transmission occurred prior to symptom onset and that mask use, disinfection and social distancing were effective in preventing COVID-19 (48). (Critical RoB)

In educational settings, a retrospective analysis following a school outbreak after reopening in September 2020 in Hamburg, Germany investigated teacher and students' condition/behavior (e.g., time spent speaking, distance to students, mask use) as well as spatial conditions/ventilation across different classrooms where transmission occurred. Authors concluded that factors contributing to spread of infection were "long-time exposure of pupils without mouth/ nose protection in crowded and poorly ventilated classrooms"; however, the individual and relative contribution of different parameters was not quantified (Critical RoB) (63). In a cross-sectional survey of directors of state secondary/high schools in Pamplona, Spain nine of eleven schools provided information and reported no cases of SARS-CoV-2 transmission in classrooms (Critical RoB) (55). A cross-sectional study examined the association between SARS-CoV-2 incidence and public health measures implemented at elementary schools in November and December 2020 in Georgia, United States. Among 169 schools, those that implemented ventilation improvements (n=87) showed reduced risk of SARS-CoV-2 incidence [RR, 0.61, (95% CI 0.43–0.87)]. Based on 123 schools with available data, the following associations were found for reduced risk of SARS-CoV-2 incidence compared to no ventilation improvements (n=37): dilution methods only (opening doors, opening windows, or using fans; n=39, 0.65, (95% CI 0.43–0.98)] (Critical RoB) (60). In a modelling study in an educational building setting, classrooms with CO_2 sensors for ventilation control exhibited better efficiency, indicating improved air quality and potentially lower transmission risk (53).

HVAC types, modes and adjustments: Three studies compared Mixing Ventilation (MV) versus Displacement Ventilation (DV). A modelling study reported that across indoor spaces, DV lowers average infection risk by 26%, while partitions reduce risk by approximately 46% (33). One modelling study reported that incomplete MV increases infection risk with temperature differences, with a notable 15% rise at lower ventilation rates. DV shows underestimation in the single-zone model, especially when the susceptible person is standing. Protected zone ventilation (partition of zones with mixed ventilation) reduces infection risk in the protected zone but increases it in the polluted zone (64). One study assessed aircraft cabin ventilation systems' efficacy in preventing SARS-CoV-2 transmission. While DV concentrated particles near windows, MV led to higher infection probabilities near aisles. Despite DV's superior pollutant removal, MV showed localized advantages in reducing contamination risks. Additionally, higher inlet velocities correlated with reduced infection probabilities, suggesting increased gas displacement's potential to lower transmission risks in aircraft cabins (56).

Six studies addressed interventions focused on rebalancing HVAC systems to increase airflow/ air velocity. In office buildings, results from one study indicate a low infection probability of less than 5% for full-time and part-time operation modes, suggesting both are effective in minimizing SARS-CoV-2 transmission risk among indoor personnel (47). In retail settings, Ho et al showed that increasing the percentage of fresh air in the supply air (by 10%, 50%, 100%) resulted in lower probability of infection (by 11%, 37%, and 51%, respectively) (57).

In classrooms, maintaining a high and constant air exchange rate (AER) through MV rapidly decreases quanta concentration, individual infection risk, and indoor CO_2 levels. The study underscores the importance of constant airflow for achieving an event reproduction number (R_{event}) below 1, crucial for minimizing the spread of airborne infectious diseases like SARS-CoV-2 in classroom settings (50). In an educational building, increasing ventilation capacity from 50% to 80% significantly reduced infection probability, highlighting the efficacy of higher ventilation rates. (53).

In transport vehicles or hubs, two modelling studies assessed these interventions. In passenger cars, higher air speeds from the HVAC system correlated with reduced contaminated particle concentration. The study concludes that enhancing ventilation systems decreases the likelihood of contracting SARS-CoV-2. Increasing air velocity improves fresh air circulation, displacing contaminated air and reducing particles concentration, thus mitigating transmission risk (51). In subway stations and carriages, MV systems exhibit infection risks exceeding 3%, decreasing with lower supply air velocity. Supply Fan Rotatory Controller (SFRC) reduces infection probability by at least 2%, while SFRC-2 achieves infection risks below 0.4%, recommending its use for improving air quality and reducing passenger infection probability when combined with optimized supply air parameters (52).

Two modelling studies compared ventilation control strategies. One in multi-family buildings reported that the probability of infection is lower with BV (max. 1.15%) and higher with RH-DCV (max. 2.04%), compared to 1.65% max. with the VE (58). In indoor settings, one modelling study proposed a model with a smart ventilation control strategy based on occupant-density detection for infection prevention and energy efficiency. Compared to traditional fixed ventilation, the smart strategy achieves 11.7% energy savings while reducing infection probability to 2%. Additionally, demand-controlled ventilation (DCV) mode achieves a 66.6% energy saving and lowers infection probability to 8.5%, 4% lower than fixed ventilation (49).

In car cabins, ventilation modes showed varying effectiveness; windshield defrosting mode exhibited lower infection risk compared to front mode (15).

SARS-CoV-2 viral concentration in air

In community settings, two studies (42,65) reported on the reduction of SARS-CoV-2 concentration in air outcome.

Opening windows: In residential settings, opening windows for more than 50% of the sampling period significantly increased CT values (indicating reduced viral load) in a cohort study. This suggests that increased ventilation from open windows halves the detectable viral load in rooms, with an average CT value of 34.4 when windows are open compared to 33.2 when closed (42). (Critical RoB)

Increasing inlet velocity: One modelling study in office environments reported that increased inlet velocity emerged as the most influential factor, consistently reducing pathogen concentration across various room designs and parameter ranges (65).

Influenza transmission and infection risk

CO2 based airing: One modelling study found that all ventilation techniques, including both mechanical and NV, effectively reduced the airborne transmission of seasonal influenza in classrooms, with the required AER < 0.1 h^{-1}. This indicates a negligible transmission potential of influenza in classrooms, even with low ventilation, due to its low emission rates compared to SARS-CoV-2 (50).

Effectiveness of different filters and filter ratings to use in a mechanical ventilation system in community-based settings

Overall, 10 studies (11,12,19,20,30,33,37,39,45,66) that addressed different filters and filter ratings in MV systems in community settings were found (educational=3; transport, vehicles and hubs=1; workplaces=1; superspreading events=1; and other non-specified indoor settings=4). All of the studies were modelling designs (n=10). SARS-CoV-2 was the most reported viral infection (n=9), followed by measles (n=1). No studies were found that evaluated influenza or RSV. Transmission reduction/infection outcome was the most frequently assessed (n=9), while viral concentration in air was assessed in only one study. All studies evaluating the effectiveness of filters were conducted with modeling methods, so RoB was not assessed.

The characteristics and findings of each study that assessed the primary outcome are presented in Table 2, and for the secondary outcome are presented are presented in Table 4.

SARS-CoV-2 transmission and infection risk

Eight modelling studies (12,19,20,30,33,37,39,66) reported on SARS-CoV-2 transmission outcome in different settings: educational (n=2), transport vehicles or hubs (n=1), superspreading events (n=1), and non-specified indoor settings (n=4).

Upgrading HVAC filter efficiency: All the studies included (8/8) reported a benefit of upgrading central HVAC filter efficiency. In educational settings, rooms with MERV-13 filters showed significantly lower SARS-CoV-2 PCR counts compared to those with MERV-11 filters ($p < 0.0012$) (39). Implementing MERV-13 filters proved most effective, reducing infection risk by over 30% compared to increased ventilation or hybrid learning. For pre-kindergarten schools, MERV-13 filters alone maintained infection risk below 1% throughout the year. Other school levels required combined strategies for similar risk reduction (12).

In passenger railcars stationary and in motion MERV-13 filters alone reduced exposure probability by 41%, while adding a high-efficiency particulate air (HEPA) purifier had no significant effect on exposure probability (67).

In superspreading events setting, filtering re-circulated air can lower transmission risk, but increasing this effect is unlikely to compensate for the elevated risk attributable to increased horizontal air-change rates. Logit scale estimates show air change rate's positive association with transmission risk and filtration rate's negative association (20).

Across different indoor scenarios, improving filter MERV ratings significantly lowered infection rates (19). Upgrading from MERV-8 to MERV-11 reduced exposure risks by 29%, and to MERV-13 by 36%. MERV-11 and MERV-13 filters reduced individual exposure risks to 1.30% and 1.22%, respectively (37). Filtration with MERV-8 filters reduced infection risk from 1.5% to 0.2%, while MERV-13 lowered it to 0.01%. Filtration's impact is comparable to OA fraction increase (30). Another modelling study found that higher-efficiency filters, like HEPA, can reduce infection risk equivalent to 100% OA supply (33).

SARS-CoV-2 viral concentration in air
Upgrading HVAC filter efficiency: In a modelling study in an office building, HEPA filtration showed the greatest virus concentration reduction, followed by MERV-13 and MERV-10. HEPA's efficacy was limited by fan capacity. On hot days, OA supply significantly reduced virus concentration, especially with MERV-10 filtration. Seasonal variations influenced strategy effectiveness, with MERV-10 and MERV-13 less effective in hot weather (45).

Measles transmission and infection risk
Upgrading HVAC filter efficiency: One modelling study found that in U.S. schools, upgrading to MERV-13 filters and HEPA filters reduced infected students by 28% and 33% respectively (11).

Effectiveness of Portable Air Cleaners (PAC) in community-based settings

Overall, 6 studies (11,33,37,68–70) that addressed PAC interventions in community settings were found (educational=2; retail=1; residential=1; and other non-specified indoor settings=2). Most of the studies were modelling designs (n=3), followed by cohort (n=1), crossover randomized controlled trial (RCT) (n=1), and quasi-experimental (n=1). SARS-CoV-2 was the most reported viral infection (n=5), followed by measles (n=1). No studies were found that evaluated influenza or RSV. Transmission reduction/infection outcome was the most frequently assessed (n=5), while viral concentration in air was only assessed in one study. The RoB of studies without modelling was critical in the cohort study, moderate in the quasi-experimental and high in the cross-over RCT.

The characteristics, findings and assessment of RoB of each study that assessed the primary outcome are presented in Table 1 for primary studies, and in Table 2 for modelling studies. The characteristics, findings and assessment of risk of each study that assessed the secondary outcome are presented in Table 3 for primary studies and in Table 4 for modelling studies.

SARS-CoV-2 transmission and infection risk

Four studies reported on SARS-CoV-2 transmission outcome (33,37,68,69), including modelling designs (n=2), cohort (n=1) and crossover RCT (n=1). Studies were conducted in retail (n=1), residential (n=1) and non-specified specified indoor (n=2) settings. 3/4 studies reported a benefit of PAC interventions.

Implementation of air purifiers and upper-room UVGI: One descriptive epidemiological study examined the effectiveness of PAC on secondary attack rates based on outbreaks at two restaurants in Hong Kong in February and December 2021. During that time, the government mandated enhancements of indoor air dilution in restaurants requiring at least 6 ACH or installation of air purifiers. The first outbreak occurred before the mandated enhancements in a restaurant with ACH of 1.2; the second outbreak occurred after the mandate in a restaurant that had installed 14 UV-C air purifiers at ceiling level with ACH of 4.6. The secondary attack rate in the second restaurant was significantly lower (2.6% vs 33.7%, $p<0.001$). Authors concluded that the air purifiers significantly reduced the secondary attack rate; however, other public health measures (availability of vaccines) were not considered (Critical RoB) (68).

PACs with high-efficiency particulate air (HEPA): In a quasi-interventional study in 32 kindergartens in Germany, portable HEPA filters[1] were installed in 10 kindergartens while 22 served as controls. The period prevalence of COVID-19 (Omicron variant) was 236 per 1000 children, ranging from 0 to 869 in intervention groups and 0 to 540 in control. For childcare workers, the prevalence was 529 per 1000 in controls and 1193 per 1000 in intervention. However, the difference did not reach significance (Moderate RoB) (69).

Increasing PACs capacity with HEPA: One modelling study in indoor settings reported that PACs with higher capacities (>17 m3/s) effectively reduce exposure risks below $R0 < 1$. PACs with airflow rates of 0.46 to 1.45 m3/s lower risks to 1.73% to 1.51%, while one with 17 m3/s achieves 0.51%, meeting an acceptable risk level (37).

Personal ventilation: One modelling study in indoor settings, reported that personal ventilation (PV) shows a substantial 67% average risk reduction (33).

Standalone air cleaners: Standalone air cleaners vary in effectiveness, with reductions ranging from under 10% to over 85%, averaging around 31% (33).

SARS-CoV-2 viral concentration in air

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[1] Authors refer to standalone portable air cleaners. And state that "CADR of the air cleaners in this study is determined by the room area with a reference of 12 m 3/h per square meter".

PACs with HEPA: In a randomized crossover trial in New Jersey, USA, air filtration with PACs reduced SARS-CoV-2 RNA presence in homes of COVID-19 patients. During sham periods (periods where the filter was removed), 44% of air samples were positive, decreasing to 25% with PACs. Bedrooms and living rooms showed reduced viral RNA presence during filtration periods (High RoB) (70).

Measles transmission and infection risk

Doubling Clean Air Delivery Rates (CADR) of air purifiers: One modelling study reported that in schools, air purifiers with CADR of 400 cubic feet per minute (CFM) reduced infections by 18% (from 45% to 37%), while doubling to 800 CFM increased effectiveness (reduction from 45% to 31%), reducing infections by 31% (11).

Effectiveness of different environmental conditions (e.g. temperature and humidity) to target for optimal ventilation in community-based settings

Overall, 7 studies (13,14,36,65,71–73) that addressed different environmental conditions to target for optimal ventilation in community settings were found (educational=2; retail=1; residential=1; workplaces=1; and other non-specified indoor settings=2). Study designs included modelling (n=6), and cohort (n=1) studies. SARS-CoV-2 was the most reported viral infection (n=6), followed by influenza (n=2). No studies were found that evaluated measles or RSV. Transmission reduction/ infection outcome was the most frequently assessed (n=6), while viral concentration in air was assessed in only one study. RoB in the cohort study was critical.

The characteristics, findings and assessment of RoB of each study that assessed the primary outcome are presented in Table 1 for primary studies, and in Table 2 for modelling studies. The characteristics of each study that assessed the secondary outcome are presented in Table 4 for modelling studies.

SARS-CoV-2 transmission and infection risk

Five modelling studies (13,14,36,71,73) reported on SARS-CoV-2 transmission outcome. Studies were conducted in retail (n=1), educational (n=2) and non-specified indoor (n=2) settings.

Relative humidity (RH): In educational settings, results of one study indicated that indoor RH had minimal impact (36). In another modelling study, humidification to moderate RH levels (40%–60%) did not significantly reduce infection risk compared to increased ventilation with OA. RH effects varied based on ventilation rate and particle size. At low ventilation rates, RH changes had minimal impact, while higher rates rendered RH almost ineffective. Increasing ventilation was far more effective than RH adjustments in reducing SARS-CoV-2 airborne levels (14).

In other indoor settings, one modelling study analyzed indoor RH's impact on infection risk for five respiratory viruses. RH ranges of 20–80% and temperatures of 20–25 °C were considered. In the case of SARS-CoV-2, the effect of humidity is not monotonic. Although an increase in humidity from 20% to 37%, especially with longer exposure times, increased the risk of infection, an increase from 37% to 70% decreased it. Once the ventilation rate increases, it was observed that RH's effect would become negligible (13). In a mechanically ventilated room, with all the associated complex air movement and turbulence, increasing the RH may result in reduced airborne exposure. However, this effect may be so small that other factors, such as a small change in proximity to the infected person, could rapidly counter the effect (71).

Temperature: One study found that having a low-heat source in restaurants compared to not having it increased infection risk, finding that low-temperature heat sources [2] significantly elevated infection risk by 190.9% and 99.6% under displacement and mixing ventilation, respectively, compared to no heat source. With high-temperature heat sources, displacement is notably more effective than MV, reducing infection risk to only 12.3% of that observed with MV (73). In mechanically ventilated indoor rooms, the impact of temperature was complex, showing both positive and negative correlations with exposure depending on distance from the infected person. While temperature increase generally raised exposure, exceptions occurred, particularly at 2–3 m (71).

SARS-CoV-2 viral concentration in air

Inlet temperature: inlet temperature showed significant effects on CO_2 mass fraction, particularly in smaller volumes, indicating its potential in controlling pathogen transmission. However, the relationship between temperature and concentration was non-linear (65).

Influenza transmission and infection risk

Two studies evaluated influenza transmission in community settings:

Temperature: One cohort study included 311 children under 12. They found that having a heated bedroom[3] was associated with lower odds of influenza infection [aOR, 0.43 (95% CI, 0.26–0.71)]. Adjusting for additional factors, such as influenza vaccination and previous respiratory issues, still showed reduced odds [aOR, 0.55 (95% CI, 0.32–0.94)] (Critical RoB) (72).

RH: One modelling study analyzed the impact of indoor RH on infection risk for five respiratory viruses. RH ranges of 20–80% and temperatures of 20–25 °C were considered. The infection risk probability decreased with higher RH in the case of airborne influenza. The effect of RH depended on the exposure time and ventilation rate—the shorter the exposure time and the higher the ventilation rate, the lower impact of RH on the infection risk. At a ventilation rate of 6 h^{-1}, the effect of RH can be considered negligible. (13).

Effectiveness of different building/room designs (e.g. number and position of mechanical air supplies, exhausts, windows, and doors) and ventilation types in building designs (e.g. cross ventilation, single-sided ventilation) for airflow in community-based settings

Overall, nine studies (65,74–81) that addressed different building/room designs and ventilation types in building designs in community settings were found (educational=2; residential=1; workplaces=2; and other non-specified indoor settings=4). Most of the studies were modelling designs (n=7), followed by cross-sectional (n=2). SARS-CoV-2 was the only reported viral infection (n=9). No studies were found that evaluated influenza, measles or RSV. Transmission

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[2] Dishes below room temperature, like bar and coffee shops, where 4 °C was defined as the temperature of the low-temperature heat source; dishes with high-temperature products, like hotpot restaurants, where the boiling point of the water under atmospheric pressure is selected as the temperature; and dishes with ambient temperatures, like Western restaurants.

[3] Authors asked about the use of a heating system in the children's bedroom ('Do you use heating equipment in your children's bedroom in winter?')

reduction/infection outcome was the most frequently assessed (n=7), while viral concentration in air was assessed in two studies. The RoB in the cross-sectional studies was critical in one of them and moderate in the other.

The characteristics, findings and assessment of RoB of each study that assessed the primary outcome are presented in Table 1 for primary studies, and in Table 2 for modelling studies. The characteristics of each study that assessed the secondary outcome are presented in Table 4 for modelling studies.

SARS-CoV-2 transmission and infection risk

Seven studies (75–81) reported on SARS-CoV-2 transmission reduction outcome, including modelling (n=5) and cross-sectional designs (n=2). Studies were conducted in educational (n=2), residential (n=1), and other indoor settings (n=4).

Building openings optimization: 5/5 studies found a beneficial effect of optimizing building openings. A field study examined environmental factors in a convenience sample of 38 homes of recovered patients in Bandung City, Indonesia (78). Homes were categorized as whether or not they met government guidelines for a "healthy house"; for ventilation, the healthy standard was defined as percentage of room area ≥10%. Bivariate analyses showed that ventilation was significantly associated with transmission rate (i.e., number of family members having COVID-19 relative to number in house and categorized as low 0-50%, intermediate 50-99% and high 100%). Authors found a determination coefficient of 0.272 indicating the proportion of overall variation in transmission that is explained by the linear relationship with ventilation (Critical RoB).

In educational settings, one study compared, through a modelling study, various window opening configurations, noting their potential to enhance ventilation efficiency and reduce infection risk. Installing window-integrated fans further improved ventilation, reducing infection probability. Authors concluded that both interventions effectively improved ventilation in naturally ventilated classrooms, particularly during transitional seasons (79). The impact of building openings' design parameters on indoor virus infection rates was investigated in a kindergarten. Through parametric optimization, they reduced the average infection rate by 3%, achieving a healthier indoor environment with lower respiratory epidemic risks. Post-optimization, they observed a significant decrease in infection rate variance, with reductions of 44.72% to 74.62%, compared to pre-optimization values, indicating improved consistency in infection risk distribution within the space (75).

In other indoor settings, one modelling study in multi-storey buildings reported that while louvers slowed airflow, they maintained ventilation effectiveness crucial for pollutant dispersion. Regarding SARS-CoV-2 transmission, inter-unit infection risk rose from 7.82% to 26.17% for windward shading and from 7.89% to 22.52% for leeward shading (81). In lecture rooms with retrofit ventilation systems, while natural ventilation (NV)[4] can suppress viral growth under certain conditions, it may not consistently prevent airborne transmission of respiratory viruses like SARS-CoV-2. Poorly performing NV systems[5] could lead to higher infection risk, but correctly designed systems can mitigate this risk. Retrofit scenarios with ventilation systems decrease average infection

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[4] Authors define NV as in described by Krarti, 2018 (82) where "Natural ventilation relies on natural forces: wind from the surrounding environment as well as buoyancy forces that develop due to temperature gradients within the building."

[5] **Scenario 4:** Retrofit: Yes; Ventilation type: Existing; Opening type: Top hung (outward); Infiltration: Retrofit.

risk, likely suppressing virus growth, indicating their effectiveness in reducing airborne transmission (77)

Repositioning supply/exhaust diffusers: In a carnival event in Gangelt, Germany, on February 15, 2020, out of 411 participants, nearly half were infected. Among the factors evaluated, proximity to air inlets and air outlets was studied; however, no significant statistical association was found between these and increased risk of infection (Low RoB) (80). One modelling study found a benefit of repositioning supply/exhaust diffusers to create directional airflow during a mass gathering event, two ventilation versions were compared, Ventilation Version 1 with better airflow reduced the average risk of transmission by 28%, compared to Ventilation Version 2. The magnitude of the effect in reducing the risk of transmission varied depending on the incidence of the disease and stricter hygiene practices. (76).

SARS-CoV-2 viral concentration in air

Two modelling studies (65,74) reported on SARS-CoV-2 concentration reduction in air outcome. Studies were conducted in workplaces and reported on multiple interventions in building/room designs.

Room size: One study reported that increasing room size by 20% reduced maximum quanta levels by 18%. Separate workspaces increased quanta levels in open offices by 57%. Better NV decreased quanta levels, particularly in meeting rooms, while enhanced MV reduced levels across all spaces. Combining improved NV with reduced meeting durations reduced maximum CO_2 levels by 31% and quanta levels by 65%, highlighting synergistic effects in mitigating IAQ issues. Implementing office partitions was associated with increased viral concentrations (74).

Repositioning supply/exhaust diffusers: One modelling study in workplaces examined the effects of room dimensions and the location, position, speed, and temperature of the inlet and outlet of the ventilation system. They reported that while inlet velocity was the most influential factor, inlet and outlet positions also played a role, particularly when aligned with airflow patterns. Directing the air flow towards the contaminant source was very effective. Room dimensions had minimal impact on pathogen concentration, suggesting that airflow direction is a key determinant of pathogen spread in indoor environments (65).

Effectiveness of different combinations of ventilation and filtration strategies in community-based settings

Overall, 15 studies (11,12,19,50,59,60,67,79,83–89) that addressed combinations of mitigation interventions in community settings were found (educational=8; transport, vehicles and hubs=2; workplaces=1; and other non-specified indoor settings=4). Most of the studies were modelling designs (n=14), followed by cross-sectional (n=1). SARS-CoV-2 was the most reported viral infection (n=14), followed by measles (n=1). No studies were found that evaluated influenza or RSV. Transmission reduction/infection outcome was the only one assessed. RoB in the cross-sectional study was critical.

The characteristics, findings and assessment of RoB of each study that assessed the primary outcome are presented in Table 1 for primary studies, and in Table 2 for modelling studies.

SARS-CoV-2 transmission and infection risk

14 studies (12,19,50,59,60,67,79,83–89) reported on SARS-CoV-2 transmission reduction outcome, including modelling (n=13) and cross-sectional designs (n=1). Studies were conducted in educational (n=7), transport vehicles or hubs (n=2), workplace (n=1), and other indoor settings (n=4).

Ventilation + air filtration: In a modelling study in educational settings, non-pharmaceutical interventions (NPIs) like social distancing and ventilation upgrades in mitigating SARS-CoV-2 transmission in schools were investigated. Findings reveal that ventilation and air filtration interventions resulted in a significant reduction (>28%) in mean transmission risk. Comparing infectious virus removal rates (IVRR) of 1 vs 2.2, ventilation and air filtration interventions reduce mean transmission risk by 25% (89). One cross-sectional study examined the association between COVID-19 incidence and public health measures implemented at elementary schools in November and December 2020 in Georgia, United States. Among 169 schools, those that implemented dilution and filtration +/- purification [opening doors, opening windows, or using fans, and using HEPA filters with or without using UVGI; n=31, 0.52, (95% CI 0.32–0.83)] showed reduced risk of COVID-19 incidence. (60).

Increase ACH + Upgrade central HVAC filter efficiency: In educational settings combinations of increased ventilation and MERV-13 filters, with or without hybrid learning, effectively maintained infection risks below 1% in elementary and combined schools. If MERV-13 filters are not viable, switching part of the student body to online learning achieved similar risk reduction (12). In PreK-5 schools infection risk can be limited below 1% by increasing ventilation rates with air filtration. However, achieving this in middle and high schools requires unrealistically high ventilation rates. Partial online learning may be needed to maintain acceptable infection risk levels and lower ventilation rate requirements, thus reducing energy costs (83). In other indoor settings, increasing ACH, FOA, and filter efficiency consistently reduced infection risk, with mechanical filtration (MERV-8 filters) notably effective (19).

Upgrade HVAC filters + HEPA filtration: In passenger railcars (stationary and in motion), which under standard conditions use MERV-8 filters, when the filter is upgraded to MERV-13, the exposure probability was reduced by 41%. When the filter is upgraded to MERV-13 and a HEPA air purifier is used in the cabin, the exposure probability was reduced to 50%, although ., higher filter efficiency raised operational and capital costs, and under standard conditions, adding a HEPA purifier had no significant effect on exposure probability (67).

Increase VR + CO2-based airing: In a modelling study, authors proposed a combined approach of MV and manual airing, leveraging CO_2 monitoring for feedback control in classrooms. By integrating mechanical systems' consistent airflow with manual adjustments based on CO_2 levels, the mechanical system offered effective ventilation, whereas mechanical systems alone may have been insufficient. The approach targets an event reproduction number (R_{event}) below 1, indicating its potential to mitigate airborne disease spread in classroom settings, particularly during pandemics like COVID-19 (50).

Increase ACH + UVGI: In a modelling study in large office buildings under varied ventilation/ disinfection strategies, combining 100% OA with Rheem's third generation products (RM3) UV-C units likely yielded the most significant risk reduction (87).

PAC + Mitigation strategies: For college classrooms, the highest transmission risks occurred without ventilation or mitigation (~25% mean), while the lowest risks (~3%-5% mean) involved combined face coverings, ventilation, and air purification. Elementary classrooms showed lower risks. Improved ventilation systems and strategic air purifier use significantly reduced transmission probabilities. Combining interventions proved more effective, but exceeding seven measures provided no added benefit, especially concerning highly transmissible variants like Delta (84).

Hybrid ventilation systems: In residential and educational buildings, simulations in three climates showed varying impacts of control strategies on energy demand and infection risk. NV dominance during cooling seasons led to significant energy savings. Enhanced NV reduced infection risk, indicating hybrid systems' potential for maintaining healthy indoor environments while reducing energy consumption. Overall, well-regulated control strategies can optimize hybrid ventilation systems for dual benefits (88). Another study reported that mixed ventilation optimized air exchange in indoor settings but could not eliminate transmission risk entirely. Ventilation type III (Mixed ventilation with optimization) exhibited the lowest risk. Despite improvements, no ventilation method alone fully mitigated transmission risks, highlighting the need for comprehensive preventive measures considering space configuration and operational strategies (59). In Tokyo Metro trains the combination of open windows and AC/fan turned on, reduced infection risk for a single passenger facing a talking infected person to 5.0×10^{-6} from 8.5×10^{-5} (when windows are closed, and AC/fan is off). Risk in a train car decreased by 91–94% when windows were open and AC/fan was on compared to closed windows and AC/fan off, across varying community infection rates, commute times, and passenger numbers (86).

Optimization of Window Openings + Integration of Window-Integrated Fans: In a modelling study, by assessing ventilation efficiency and infection probability in a Slovenian educational building, installing window-integrated fans significantly enhanced ventilation, reducing infection risk (79).

Dilution ventilation + ventilative cooling (DVVC): In indoor settings, a modelling study proposed a novel ventilation control strategy combining dilution ventilation and ventilative cooling. Results showed that existing fan flow rates were not sufficient to maintain infection risk below 1%. Despite peak occupancy, ventilation rates reached their maximum without further reducing infection risk, highlighting limitations in existing ventilation strategies for COVID-19 mitigation. DVVC + Low Specific Fan Cooling (LSFP) effectiveness was found dependant on the occupation (85).

Measles transmission and infection risk

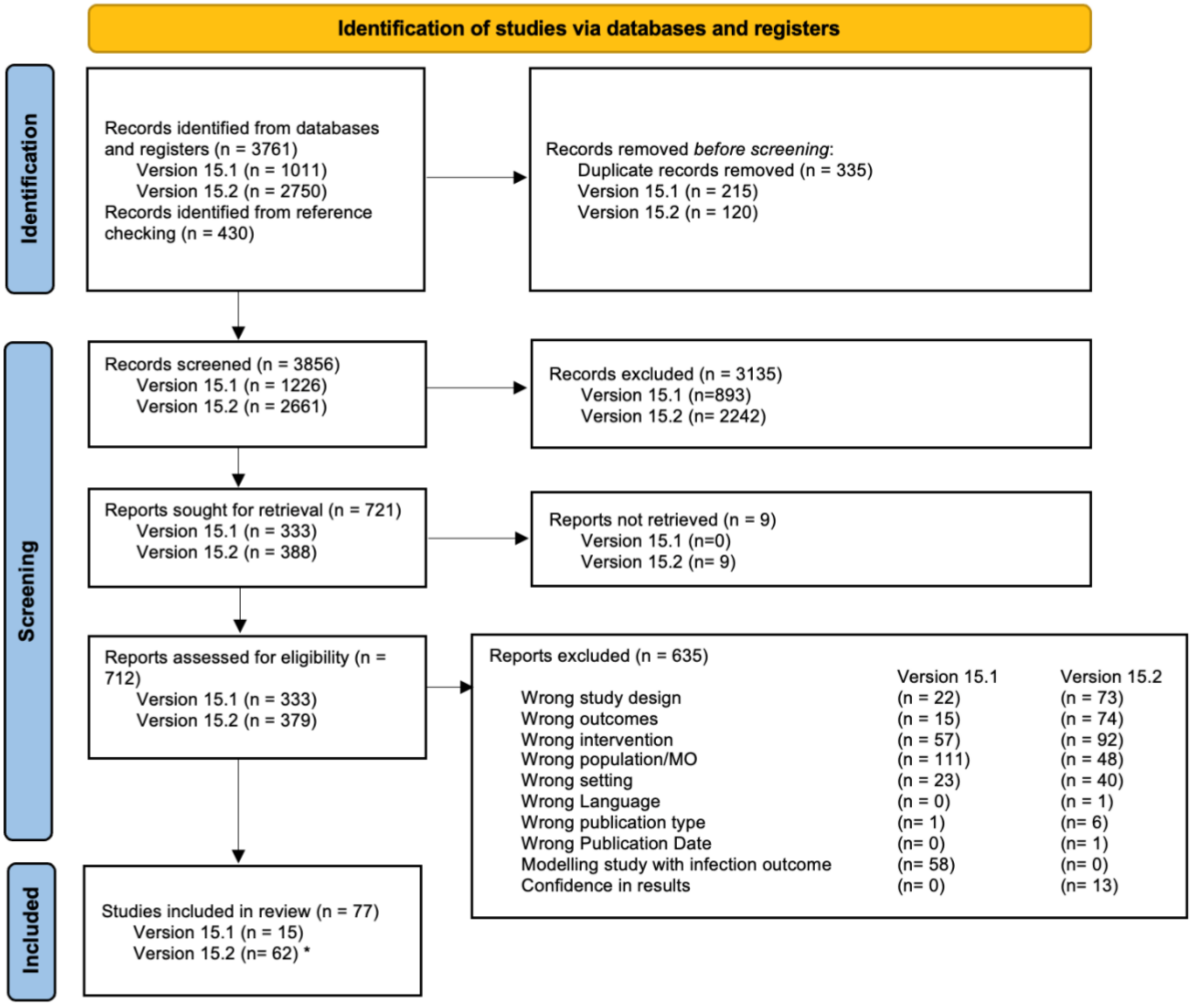
Increase VR +Upgrade central HVAC filter efficiency + Upgrade air purification: In one modelling study, combining interventions (all advanced control scenarios: upgrading to HEPA filters, ventilation rates higher than the minimum requirements, doubling CADR to 800 CFM) reduced infections by up to 56%, highlighting the efficacy of integrated control strategies in mitigating airborne disease transmission in schools (11).

Summary of findings about unintended consequences of VAFD strategies used to reduce transmission of respiratory infectious diseases (RIDs) or risk of infection (Primary Outcome).

One study was identified that reported on unintended consequences of PAC. The characteristics, findings and assessment of RoB of the study are presented in Table 5.

The study involved cross-sectional surveys of students and teachers after installation of portable HEPA air purifiers in classrooms in a school in Germany (90). The survey was completed twice: the first survey was completed in summer (July 2021) and in the months prior the sound pressure of the devices was ~55 decibels; the second survey was completed in winter (December 2021) and in the months prior the sound pressure was ~47 decibels. Authors noted that the "German Technical Rules for Work Environments (GMBl 2018) recommend that the additional noise level in school classrooms should be kept below 35 dB(A) and is not allowed to exceed 55 dB(A)." For the first survey (summer), approximately half of students and teachers found noise levels disturbing and a majority found communication in class difficult or impaired; however, a minority found their ability to concentrate to be bad. For the second survey (winter), approximately half of students and teachers found noise levels not disturbing or only marginally disturbing and a majority found communication was possible without problems or usually possible; a majority also found ability to concentrate was good or very good. More students supported using air purifiers in response to the second survey compared to the first; the majority of teachers supported use of air purifiers in both surveys. Authors concluded that noise levels of air purifiers need to be considered, and acceptance can be improved when noise level is reduced. (Critical RoB)

Figure 1: Flow diagram for study identification (from Preferred Reporting Items for Systematic Reviews and Meta-Analyses, PRISMA)



	Version 15.1	Version 15.2
Wrong study design	(n = 22)	(n = 73)
Wrong outcomes	(n = 15)	(n = 74)
Wrong intervention	(n = 57)	(n = 92)
Wrong population/MO	(n = 111)	(n = 48)
Wrong setting	(n = 23)	(n = 40)
Wrong Language	(n = 0)	(n = 1)
Wrong publication type	(n= 1)	(n= 6)
Wrong Publication Date	(n= 0)	(n= 1)
Modelling study with infection outcome	(n= 58)	(n= 0)
Confidence in results	(n= 0)	(n= 13)

V1 = version 3 (February 10, 2023 – March 3, 2023)
* 28th studies excluded in LES 15.1, included in LES 18.2
MO= Microorganisms

Table 1: Summary of primary studies reporting on effectiveness of VAFD in reducing RIDs transmission, infection risk or probability (n=13)

Last updated March 28th 2024

<table>
<tr><th>RIDs</th><th>Author, Year Country</th><th>Setting and time covered</th><th>Study characteristics</th><th>Summary of key findings in relation to the outcome(s)</th><th>RoB</th></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Baumgarte et al., 2022 (63)

Germany</td><td rowspan="2">School outbreak in Hamburg, Germany after reopening in 2020.

September 2020</td><td rowspan="2">Design: retrospective analysis of epidemiological data, using and validating the data of the health department and the school management and interviews

Intervention: regional public health service guidelines including recommendation to ventilate several times a day through fully opened windows via intermittent or cross ventilation, usually during breaks and only occasionally during class

Sample: 368 students; 117 staff

Key outcomes: COVID-19 attack and infection rate.</td><td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td></tr>
<tr><td>Total PCR positive: 33 (9%) students; 3 (1.7%) staff

<table>
<tr><th>Classroom (day after index case was infected)</th><th>2 (day 3)</th><th>1 (day 3)</th><th>3, like 2 (day 4)</th><th>4, like 2 (day 4)</th></tr>
<tr><td># people infected / # people present</td><td>8/25</td><td>16/29</td><td>3/25</td><td>1/28</td></tr>
<tr><td># normal windows always open at breaks</td><td>2/3 lg</td><td>2/6 sm</td><td>2/3 lg</td><td>2/3 lg</td></tr>
<tr><td># always open window flaps</td><td>3/3 lg</td><td>4/6 sm</td><td>3/3 lg</td><td>3/3 lg</td></tr>
<tr><td>Open door</td><td>+/-</td><td>-</td><td>+/-</td><td>+/-</td></tr>
<tr><td>Attack rate (%)</td><td>33.33</td><td>57.14</td><td>12.5</td><td>3.7</td></tr>
<tr><td>Infection rate (1/h)</td><td>0.22</td><td>0.19</td><td>0.08</td><td>0.05</td></tr>
</table>

Authors concluded that several factors contributed to spread of infection: condition/behavior of teacher and students (e.g., amount of time speaking, distance to students, mask use) and classroom conditions (crowding, ventilation). Individual and relative effects of different variables were not quantified.

Limitations: This study was assessed as critical RoB due to confounding and intervention/exposure classification/measurement.</td><td>Critical</td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Nabirova et al., 2022 (54)

Kazakhstan</td><td rowspan="2">Tengizchevroil (TCO) oilfield in Kazakhstan

June 1 – September 15, 2020</td><td rowspan="2">Design: concurrent case-control study among TCO oilfield workers who worked on-site (standardized, structured CDC questionnaire consisting of 123 questions and study participant interviews)

Intervention: 20 individual and 22 environmental factors examined,</td><td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td></tr>
<tr><td>Adjusted odds ratios (95% CI) for environmental factors related to ventilation and COVID-19 among employees (cases n=296, controls n=536):
• Ventilation at work = [aOR, 0.68 (95% CI 0.36–1.24)].
• Air conditioner at work = [aOR, 3.95 (95% CI 1.30–13.12)] significant difference.
• Office work = [aOR, 0.93 (95% CI 0.53–1.61)].</td><td>Low</td></tr>
</table>

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			including ventilation at work, air conditioner at work, working indoors (office, kitchen, and storeroom) and working outdoors **Sample**: eight shift camps with the highest COVID-19 incidence were selected to participate in June and July 2020; intended to recruit 296 cases and 590 controls <u>Cases</u>: employees identified as COVID-19 positive by PCR test, regardless of symptoms <u>Controls</u>: two per one case patient randomly selected among COVID-19 negative employees working or living in the same shift camps during same rotation period **Key Outcomes**: COVID-19 cases	• Outdoor work = [aOR, 0.75 (95% CI 0.43–1.28)]. • Based on multivariate analysis only air-conditioning on premises was associated with SARS-CoV-2 transmission [aOR, 4.0 (95% CI 1.3–13.1)]. Authors conclude that individual factors (e.g., rare hand sanitizer use, social interactions outside of work) were main drivers of transmission, with little contribution by environmental factors. Limitations: Although this study was assessed as having a low RoB overall, it is considered that there is an unclear RoB for the measurement of exposure.	
SARS-CoV-2	Monge-Barrio et al., 2021 (55) Spain	High **schools** in Pamplona, Northern Spain with temperate climate, before and during the pandemic Indoor environmental conditions studied during March 2020 and January 2021	**Design**: Cross-sectional survey of students and teachers, and monitoring of various indoor environmental conditions **Intervention**: increased natural ventilation during post-pandemic data collection in January 2021; all schools opened all windows and doors during the break (30 minutes), at the end of each class, and at the end of the day; one school opened windows at beginning of day and not at the end of each class; during class natural ventilation determined by teacher (windows mainly closed or slightly opened depending on outdoor temperatures and type of openings)	**HVAC systems (e.g. displacement, mixing systems)** • 6/9 (67%) schools were naturally ventilated and did not have any MV or air conditioning. • 3/9 (33%) schools had MV with heating recovery ventilation; when surveyed they did not use these systems due to the noise and in one case, additional energy consumption (2 also had air conditioning but did not use). • None of the schools self-reported COVID-19 transmission. Limitations: This study presented a critical RoB in most of the aspects evaluated, especially about the measurement of outcomes, possible confounding variables, and control of confusion	Critical

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			Sample: 9 high schools **Key outcomes**: “evidence of COVID-19 infections” in classrooms reported by school directors.		
SARS-CoV-2	Wang et al., 2020 (48) China	**Homes** of families with at least one case of laboratory confirmed COVID-19 in Beijing, China February 28 to March 27, 2020	**Design**: Retrospective cohort of families; structured questionnaire including demographics, clinical information, primary case’s knowledge and attitude toward COVID-19; self-reported practices of primary case and family members; accommodation and household hygiene practices **Intervention**: multiple characteristics and practices, including ventilation duration per day (the practice of opening the window to allow convection of indoor air) **Sample**: 83 families without secondary transmission; 41 families with secondary transmission **Key outcomes**: families with and without secondary transmission, attack rate	**HVAC systems (e.g. displacement, mixing systems)** • Overall secondary attack rate in families was 23% (77/335). • Ventilation duration per day (Median, IQR in hours): overall = 2 (1-6); without transmission = 3 (1.5-8); with transmission = 1.8 (1-4). • Household ventilation duration was protective against infection in univariate analysis: [OR, 2.55 (95% CI 1.14–5.70)] for ≤1 hour per day vs >1 hour per day. • Ventilation not significant in multivariable analysis. Authors conclude that highest risk of transmission occurs prior to symptom onset and that mask use, disinfection and social distancing are effective in preventing COVID-19. Limitations: This study was based on self-assessment of some aspects, such as the use of masks and disinfection practices within homes through telephone interviews and does not mention efforts to control social desirability bias, in addition to the impossibility of explicitly verifying the compliance with these protective behaviors/interventions. The possibility of high-risk occupational and social exposures outside the home is not explicitly addressed prior to identification of the index case nor are potential confounding factors addressed. Additionally, the study does not explicitly state that all participants underwent laboratory testing.	Critical
SARS-CoV-2	Buonanno et al., 2022 (17) Italy	Pre-, primary, middle and high **schools** in Italy’s Marche region 13 September 2021 - 31 January 2022	**Design:** retrospective cohort **Intervention:** Mechanical Ventilation System (MVS) installed in schools in March 2021; consisting of single room units, most equipped with heat recovery and filters; switched on manually before class start and run constantly throughout school day; maximum air flow rates ranged from 100 to 1000 m3 h−1; with a	**Numbers of air changes per hour (ACH) for optimal ventilation** • Incidence proportion (per 1,000 students) was 4.9 (31 cases) with MVS and 15.3 (3,090 cases) without MVS. Incidence proportion ratio for the entire period was 0.32. • Based on most conservative estimate (classrooms with vs. without MVS), RR = 0.26, RRR = 0.74 (statistically significant, no confidence intervals reported) [analyses controlled for ACH, compulsory schools, number of students in classroom].	Critical

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			ventilation rate between 1.4 and 14 L s−1 student−1 **Sample:** Total = 10,441 classrooms in 1,419 schools; MVS = 316 classrooms in 56 schools; Natural (leakage of building and manual opening of windows) = 1,363 classrooms in 10,125 schools; classrooms had an average occupancy of 20 students (total student population 205,347) **Key outcomes:** incidence cases and incidence proportions (number of positive students per 1,000); both presented as number of positive students counted only within clusters for classrooms with and without MVSs and for 12 different sub-periods.	• Analysis by time period showed effectiveness of MVS greater during month with high incidence of infection at regional level. • Analyses showed increased effectiveness with higher ACH. Limitations: This study presented a critical RoB in relation to the measurement of outcomes and control of possible confounding variables.	
SARS-CoV-2	Pokora et al., 2021 (31) Germany	**Meat and poultry processing plants** in Germany June to September 2020	**Design**: cross-sectional study (self-administered questionnaire). **Intervention**: multiple risk factors including ventilation, quantified as outdoor air flow per employee in a working area = outdoor air flow / (number of employees in a working area / number of shifts in the working area). **Sample**: 22 companies for 19,027 employees, including 880 COVID-19 infected workers divided into the following groups: 7 = many infected workers prevalence between 2.94 to 35.10 infections per 100 employees 5 = with fewer than 10 infected workers 10 = with no infected workers	**Numbers of air changes per hour (ACH) for optimal ventilation**	
				Results of multivariable logistic regression for maximum outdoor air flow (OAF) per employee: • when delivery, stunning/slinging/hanging, and slaughter areas were excluded from analysis (these areas have a process related high ventilation rate) (n=2,334), [aOR, 0.996 (95% CI 0.993–0.999)]; including interaction term for temperature and OAF, [aOR, 0.984 (95% CI 0.971–0.996)].	Critical
				HVAC systems (e.g. displacement, mixing systems)	
				Based on results of multivariable logistic regression analysis (for subsample of companies with many infected workers), having a ventilation system reduced chance of testing positive for COVID-19: • overall (6,522 workers): [aOR, 0.757 (95% CI 0.563–1.018)] • results also presented by type of worker: regular workers [aOR, 1.076 (95% CI 0.619–1.869)] vs. temporary and contract [aOR, 0.541 (95% CI 0.368–0.796)] Limitations: This study had a critical RoB related to confounding factors, participant selection, measurement of exposures, and outcomes.	Critical s

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			Key outcomes: COVID-19 infection		
				Numbers of air changes per hour (ACH) for optimal ventilation	
Influenza	Yang et al., 2021 (46) China	**Phase I:** included students living in 12 buildings on the Tianjin University campus from May 27, 2015, to June 20, 2015. Up to six students shared one dorm room, with room sizes ranging from 25 to 38 m^2. These dorm rooms were simple bedrooms without kitchens and bathrooms, with two public bathrooms on each floor. **Phase II:** "Case" dormitories had at least one occupant self-report an annual infection incidence ≥ 6 times, while "control" dormitories had all occupants with annual infection	**Design**: Phase I, cross-sectional study performed using self-administered questionnaires. Phase II nested case-control study. During inspections, indoor air temperature, Relative Humidity (RH), and CO_2 concentrations in dorm rooms were measured for 24 hours. **Intervention**: The intervention group consisted of dorm rooms with higher ventilation rates per person, while the comparator group included rooms with lower ventilation rates. **Sample**: Phase I: 2952 students from 973 (79.8%) dorm rooms, including 42.7% female and 57.3% male students, with a distribution of PhD, master, and bachelor students at 8.9%, 37.4%, and 53.7%, respectively. The average area per person was 6.5 m^{2} Phase II: A total of 242 dorm rooms in 12 buildings were selected for inspection in both summer and winter. **Key Outcomes:** The incidence of respiratory infections (association between the environmental conditions and the prevalence).	**Ventilation Rate per Person in Summer:** The study found that a lower ventilation rate per person was significantly associated with an increased incidence and duration of common cold infections among college students during the summer. Specifically, the adjusted odds ratios for common cold infection and duration with lower ventilation rates were 1.27 and 2.36, respectively, indicating that students in dormitories with poor ventilation were more likely to report common cold infections and experience longer durations of these infections. Higher ventilation rates per hour were associated with a decrease in influenza infections among college students, with 83.2% of students in high ventilation environments reporting no influenza infections compared to 75.7% in low ventilation environments. The chi-square test indicated a significant association between high ventilation rates and reduced influenza infections (P = 0.022). However, the duration of influenza infections did not significantly differ with ventilation rates, as shown by the P-value of 0.821 in the GEE model analysis.	Moderate

Associations of infection and duration with ventilation rate in summer.

			Infection		**Duration**		**aOR (95% CI)**	**Duration ≥ 2 weeks**
			No	**Yes**	**<2 weeks**	**≥ 2 weeks**		
Influenza	Ventilation rate per hour (h^{-1})	Low	227 (75.7)	73 (24.3)	53 (70.7)	22 (29.3)	**2.38 (1.30,4.36)**	1.24 (0.37,4.15)
		High	248 (83.2)	50 (16.8)	33 (68.8)	15 (31.3)	1.00	1.00
		P-value	**0.02**		0.82			
Cold		Low	162 (51.1)	155 (48.9)	112 (76.2)	35 (23.8)	1.09 (0.72, 1.66)	1.55 (0.69.51)
		High	165 (54.3)	139 (45.7)	103 (79.2)	27 (20.8)	1.00	1.00
		P-value	0.43		0.55			
Influenza	Ventilation rate per person	Low	231 (75.7)	74 (24.3)	48 (64.9)	26 (35.1)	**2.36 (1.30,4.28)**	2.70 (0.69, 10.51)

<table>
<tr><th>RIDs</th><th>Author, Year Country</th><th>Setting and time covered</th><th>Study characteristics</th><th>Summary of key findings in relation to the outcome(s)</th><th>RoB</th></tr>
<tr>
<td></td>
<td></td>
<td>incidence <6 times.
Summer period: June 23, 2015, to July 20, 2015
Winter period: December 24, 2015, to January 23, 2016.</td>
<td></td>
<td>
<table>
<tr><td></td><td>(L/(s•person))</td><td>High</td><td>244 (83.3)</td><td>49 (16.7)</td><td>38 (77.6)</td><td>11 (22.4)</td><td>1.00</td><td>1.00</td></tr>
<tr><td></td><td></td><td>P-value</td><td colspan="2">0.02</td><td colspan="2">0.13</td><td></td><td></td></tr>
<tr><td>Cold</td><td></td><td>Low</td><td>158 (48.8)</td><td>166 (51.2)</td><td>114 (72.2)</td><td>44 (27.8)</td><td>1.27 (0.83, 1.95)</td><td>4.29 (1.63, 11.26)</td></tr>
<tr><td></td><td></td><td>High</td><td>169 (56.9)</td><td>128 (43.1)</td><td>101 (84.9)</td><td>18 (15.1)</td><td>1.00</td><td>1.00</td></tr>
<tr><td></td><td></td><td>P-value</td><td colspan="2">0.04</td><td colspan="2">0.01</td><td></td><td></td></tr>
</table>
Median value is cut point, i.e., 1.90 h^{-1} for ventilation rate per hour; 10.7 L/(s•person) for ventilation rate per person. Generalized estimating equation models, with odds ratios adjusted for gender, occupancy levels, smoking, history of allergic diseases (asthma or rhinitis) and dampness problems. Values in bold indicate statistical significance, i.e., $P < 0.05$.
Ventilation Rate per Person in Winter:
Low ventilation rates per person were significantly associated with a higher incidence of colds and influenza infections among college students in winter. The ventilation rates in rooms measured during winter were less variable, from 0.3 to 23.5 L/s per person, with a median of 4.10 L/s per person. Rooms with high ventilation rates had low RH in winter.
Combined Effects of Ventilation and Dampness:
The results, adjusted for gender, occupancy levels, environmental tobacco smoke, and history of allergic diseases, indicated that the combined effects of poor ventilation and dampness significantly increased the odds of influenza infections.
Associations of exposure to indoor dampness with common cold and influenza by using generalized estimating equation models
<table>
<tr><th></th><th colspan="2">Common cold</th><th colspan="2">Influenza</th></tr>
<tr><th></th><th>Incidence ≥ 6 times</th><th>Duration ≥ 2 weeks</th><th>Incidence ≥ 1 times</th><th>Duration ≥ 2 weeks</th></tr>
<tr><td>Visible mold spots</td><td>1.62 (1.24, 2.12)</td><td>1.49 (1.08, 2.06)</td><td>1.42 (1.06, 1.91)</td><td>1.10 (0.74, 1.65)</td></tr>
<tr><td>Visible damp stain</td><td>1.49 (1.19 1.87)</td><td>1.35 (1.00, 1.79)</td><td>1.39 (1.10, 1.76)</td><td>1.20 (0.88, 1.64)</td></tr>
<tr><td>Water damage</td><td>1.26 (0.95, 1.66)</td><td>1.52 (1.06, 2.18)</td><td>1.57 (1.18, 2.09)</td><td>1.54 (1.07, 2.19)</td></tr>
<tr><td>Suspected moisture</td><td>1.28 (1.05, 1.56)</td><td>0.96 (0.74, 1.24)</td><td>1.32 (1.08, 1.61)</td><td>0.82 (0.62, 1.08)</td></tr>
</table>
</td>
<td></td>
</tr>
</table>

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
				Odds ratios are adjusted for gender, occupancy level, smoking, hist01Y of allergic diseases (asthma or rhinitis) and opening window frequency. Values in bold indicate statistical significance, i.e., P < 0.05. Limitations: The method of measuring the results was a survey and from this the comparison groups were defined. The comparators in this study were the "case" and "control" bedrooms, differentiated by the incidence of respiratory infections among their occupants. “Case” dormitories had at least one occupant reporting a ≥6-fold annual incidence of infection, while “control” dormitories had all occupants with a <6-fold annual incidence of infection. Through the survey, some confounding factors were measured, but other relevant factors such as vaccination or time spent in the rooms were not measured.	
SARS-CoV-2 (Omicron variant)	Falkenberg et al., 2023 (69) Germany	32 **kindergartens** (daycare centres) in Rhineland Palatinate, Germany November 2021 to May 2022	**Design:** The study followed a quasi-interventional design, as no formal intervention was conducted. A charity foundation equipped kindergartens with portable air cleaners with HEPA filters installed. These kindergartens were enrolled as an intervention group. The control group was recruited from the neighbouring communities and districts. **Intervention:** DEMA-airtech air purifiers with HEPA H13 filter **Sample:** Intervention group: 10 kindergartens with 663 children were cared for by 147 childcare workers in 35 groups. Control group: 22 kindergartens with 1697 children and 374 caretakers, organised into 65 groups. **Key Outcomes:** period prevalence rate per 1000 children period prevalence rate per 1000 workers	**Portable air cleaners (Air cleaners and air purifiers)** • The period prevalence of the entire sample population was 236 per 1000 children for the time period (November 2021–May 2022). In the control group, the period prevalence ranged from 0 to 540 per 1000 children, while the period prevalence ranged from 120 to 869 per 1000 children in the intervention group. • The mean COVID-19 period prevalence rate was 372 and 186 per 1000 children in the intervention and control groups, respectively. The one-sided Wilcoxon rank-sum test indicates a p value of 0.989 and a CI from $-\infty$ to 299.7. • The period prevalence per 1000 childcare workers presents similar results. In the control group, the mean prevalence for the period from November 2021 to May 2022 was 529 per 1000 childcare workers, while it reached 1193 per 1000 childcare workers in the intervention group. The one-sided Wilcoxon rank-sum test failed to reach significance. • Authors concluded that the preventive effect of portable air cleaners with HEPA filters installed against COVID-19 in kindergarten settings was not confirmed. Limitations: The main concern arises that participants in the comparisons were not receiving similar treatment/care, other than the exposure or intervention of interest (HEPA filters). This discrepancy could introduce confounding variables, affecting the study's ability to isolate the effect of HEPA filters on COVID-19 transmission rates. If kindergartens implemented various additional preventive measures (e.g.,	Moderate

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
				mask use, ventilation practices, surface decontamination) inconsistently between the intervention and control groups, these differences could influence the outcome regardless of the filters HEPA. Such variations in treatment/care could potentially bias results, making it difficult to attribute changes in COVID-19 transmission rates directly to the use of HEPA filters.	
SARS-CoV-2 (Omicron variant)	Cheng et al., 2022 (68) China	**Restaurants** in Hong Kong with COVID-19 outbreaks before (R1) and after enhancement of indoor air dilution (R2) February 19, 2021, and December 27, 2021	**Design**: descriptive epidemiological study to evaluate the effect of mandatory enhancement of indoor air dilution in restaurants (requirement for ACH of ≥6 in seating areas of restaurants or, if not feasible, installation of air purifiers as alternate measure) **Intervention**: indoor air dilution enhancement by ultraviolet-C air purifying system (R2); 14 air purifiers mounted at ceiling level near return air grilles (post-adjustment ACH was 4.6 in seating area of R2 compared with ACH 1.2 in R1) **Sample**: customers and staff at different restaurants before and after mandatory air dilution enhancement; for R1 outbreak none of the customers or staff were vaccinated, all cases in R2 were fully vaccinated **Key Outcomes**: secondary attack rate	**Portable air cleaners (Air cleaners and air purifiers)** • Secondary attack rate among customers in R2 was significantly lower than that in R1 (3.4%, 7/207 vs 28.9%, 22/76, p<0.001) • Secondary attack rate among restaurant staff in R2 was significantly lower than that in R1 (0%, 0/22 vs 52.6%, 10.19, p<0.001) • Secondary attack rate overall was lower in R2 compared with R1 (2.6% vs 33.7%, p<0.001) Authors concluded that improvement in air dilution with installation of air purifiers and upper-room UVGI significantly decreased secondary attack rate. Limitations: This study was evaluated with critical RoB, especially for the selection of participants, the control of confounding factors and lack of clarity in aspects of measuring the outcomes and adherence of the intervention.	Critical
Influenza	Miyake et al., 2020 (72) Japan	Children's **bedrooms** in Kyushu, Japan September through November 2018	**Design:** Cohort, using two questionnaire surveys, one before the winter season in November 2018 and the second after the winter in March 2019 to evaluate whether the heating system in the bedroom was associated with respiratory diseases in the children of Japan.	**Environmental conditions to target for optimal ventilation** • Having a heated bedroom was associated with lower odds of influenza infection [aOR, 0.43 (95% CI, 0.26–0.71)] adjusted for age and sex. • Having a heated bedroom was associated with lower odds of influenza infection [aOR, 0.55 (95% CI, 0.32–0.94)] adjusted for age, sex, influenza vaccination, and previous respiratory problems.	Serious

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RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			Intervention: heating system **Sample:** 311 children under 12 years of age (155 children without heating system, 156 children with heating system) **Key outcomes:** Probability of influenza infection (aOR)	Authors concluded that using a heating system in a child's room during winter is a protective factor for influenza infection compared to not using a heating system. Limitations: This study does not have a clear and detailed description of how each intervention was handled. They relied on self-report to classify individuals into intervention or control groups, without addressing how this potential bias was controlled for. The study adjusted for influenza vaccination; does not mention monitoring for other potential RID protective interventions. The validity of the questionnaires used for data collection is unknown. It is not explicitly mentioned whether participants were free of confirmed RID infection at baseline. The study does not mention any attempt to control for social desirability bias and does not mention any verification of compliance with protective behaviors/interventions after their implementation.	
SARS-CoV-2	Oginawati et al., 2022 (78) Indonesia	**Homes** of recovered patients in Coblong District, Bandung City, Indonesia (subdistricts: Dago and Sekeloa) March to April 2021	**Design:** field study regarding the relation of residential environmental factors against COVID-19 (including temperature, humidity, brightness, ventilation size, and personal space area); using a convenient sampling method to select households that survived COVID-19 infections (questionnaires and interviews with recovered patients, and physical observations in residences) **Intervention**: ventilation size – comparing size of vent hole (assessed using measuring tape) and home's total area (bigger vent hole size = better ACH in house) **Sample**: 38 houses of survivor/recovered patients **Key Outcomes**: transmission rate in households meeting healthy ventilation standards, i.e., number having COVID-19 relative to number in house and	**Different building/room designs and ventilation types in building designs** • Number of households meeting healthy ventilation standard of ≥10% of room area = 31/38 (82%) • The requirements for the ventilation parameters for a standard healthy house independently associated with transmission of COVID-19 (p-value = 0.021) • Based on the correlation values the size of ventilation in the house is, inversely, significantly related to the transmission of COVID-19 in the house (correlation coefficient -0.522; determination coefficient 0.272 (i.e., proportion of overall variation in transmission explained by linear relationship with ventilation); p=0.002) • Ventilation was the only environmental parameter examined that had significant association with transmission. Limitations: The RoB in this study was critical especially due to the RoB due to confounding and possible selection and measurement bias.	Critical

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			categorized as low (0-50%), intermediate (50-99%) and high (100%)		
SARS-CoV-2	Wessendorf et al., 2022 (80) Germany	Carnival celebration called 'Kappensitzung' held on 15 February 2020 in Gangelt, North Rhine-Westphalia, Germany. This was an indoor event, lasted for approximately 5 hours, hosted at a small community centre measuring 320 square meters.	**Design:** cross-sectional epidemiological study conducted 51 days after a carnival celebration in the beginning of 2020. **Intervention**: Analysis of different variables such as proximity to air inlets and outlets, duration of attendance, and demographic factors among participants who tested positive or negative for SARS-CoV-2 infection, to identify potential risk factors associated with infection. **Sample**: All adults known to have attended the event were invited to participate in the study. Out of approximately 450 attendees, 411 participated in the study, resulting in a participation rate of 91.3%. **Key Outcomes**: infection rates. The assessment was conducted through serological testing for IgG and IgA antibodies and RT-PCR testing for viral RNA to confirm current or past infection.	**Different building/room designs and ventilation types in building designs** • Systematic analysis of the carnival event identified a high infection rate, with nearly half of the participants becoming infected, highlighting the event's role as a unique superspreading occurrence during the SARS-CoV-2 pandemic. • No statistical association was found between greater proximity to air outlets and greater risk of infection [aOR 1.26 (95% CI, 0.63–2.50)]. • No statistical association was found between greater proximity to air inlets and greater risk of infection [aOR 1.01 (95% CI, 0.53–1.94)]. Limitations: This study had a low RoB due to its design. The main concern is the use of a survey to measure exposure since it is an instrument susceptible to information bias. However, the authors present the results considering only the specific values, so they conclude effects in some interventions, but when considering the confidence intervals of these statistics, it is observed that in some of them the differences found are not statistically significant, for which in this summary we do not consider them as such.	Low
SARS-CoV-2	Gettings et al., 2021 (60) United States	Georgia state elementary **schools** (kindergarten through grade 5) November 16 – December 11, 2020	**Design**: cross-sectional study (self-reported cases to state public health department; online survey completed by school representatives) **Intervention**: ventilation improvements: "steps being taken to improve air quality and increase the ventilation in the school"; those who responded "yes"	**HVAC systems (e.g. displacement, mixing systems)** • COVID-19 incidence 39% lower in schools that improved ventilation, compared with schools that did not [RR 0.61 (95% CI 0.43–0.87) • Ventilation strategies associated with lower school incidence included methods to dilute airborne particles alone by opening windows, opening doors, or using fans [35% lower incidence, RR=0.65 (95% CI: 0.43–0.98)] **Combinations of ventilation and filtration strategies**	Critical

RIDs	Author, Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			were asked to select one or more of the following: opening doors/windows, using fans to increase effectiveness of open windows, installation of HEPA filtration systems in high-risk areas, or installation of UVGI in high-risk areas **Sample**: 169 (11.6% of 1,461) schools including 91,893 students with available case data (number of cases = 566) **Key outcomes**: COVID-19 cases and incidence	• COVID-19 incidence 39% lower in schools that improved ventilation, compared with schools that did not [RR 0.61 (95% CI 0.43–0.87) • Ventilation strategies associated with lower school incidence included methods to dilute airborne particles alone by opening windows, opening doors, or using fans in combination with methods to filter airborne particles using HEPA filtration with or without purification with UVGI [48% lower incidence, RR=0.52 (95% CI: 0.32–0.83)] Limitations: This study was at critical RoB due to confounding factors, participant selection, measurement of exposures, and outcomes.	Critical
Evidence gaps					
No data yet	Filters and filter ratings to use in a mechanical ventilation system				

Abbreviations: ACH = air changes per hour; aOR = adjusted odds ratio; CDC = Centres for Disease Control; CI = confidence interval; HEPA = high-efficiency particulate absorbing; IQR = interquartile range; lg = large; MVS = mechanical ventilation system; OR = odds ratio; PCR = polymerase chain reaction; RR = rate ratio; RRR = relative risk reduction; sm = small; UVGI = ultraviolet germicidal irradiation

Table 2: Summary of modelling studies reporting on effectiveness of VAFD in reducing RIDs transmission, infection risk or probability (n=55)

Last updated March 28th, 2024

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
SARS-CoV-2	Clements et al., 2023 (18)	The authors evaluated the effectiveness of interventions such as ventilation, masking, and the use of HEPA air cleaners in reducing the transmission risk of airborne pathogens, specifically in enclosed spaces. **Methodology:** The study's methodology involves using a Tracer-Scaled Bulk Aerosol QMRA Model to simulate the survival, transport, and decay of aerosolized pathogens in indoor environments, considering multiple-occupant scenarios and interventions like ventilation and masking. Various exposure scenarios were analyzed by manipulating variables such as ventilation, occupancy, masking, and dose-response curves to assess the impact on pathogen transmission risk. The effectiveness of a HEPA air cleaner in an ambulatory care room was evaluated using DNA Tracer Decay Testing, with measurements taken before and after the cleaner's installation. The methodology also accounted for particle size dependence in emission, removal rates, and	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: High-ventilation intervention in a restaurant outbreak scenario in Guangzhou, China, assumed 17.08 L/s of outdoor air supply in a 110 m^3 room with 20 adult occupants besides the emitter, eight emission events, a 75 min exposure time, an indoor temperature of 23 °C, and an indoor Relative Humidity (RH) of 50%. Compared to Baseline scenario with low outdoor air ventilation rate and occupants sitting in a "bubble" of higher pathogen concentrations created by a recirculating air conditioning unit. Adding medium-high ventilation and reducing occupancy in a high-risk scenario compared to High-risk scenario without intervention. **Key Outcomes:** Attack rate	In a restaurant in Guangzhou, the pathogen removal rate was estimated to be 0.057 min^{-1}. High tracer concentrations led to a mean 2.1% risk of large cough episodes. Adding 3.5 and 10 h−1 of ventilation in this scenario was estimated to reduce the median relative risk by 51 ± 2% and 74 ± 1%, respectively, though significant superspreader risk remained. **High-ventilation intervention** • The high-ventilation intervention was assessed to compare the predicted risk from the tracer-scaled QMRA model to the actual outbreak, where 10 of 21 individuals were infected, indicating a high attack rate (47.6%) attributed to the low ventilation rate in the baseline scenario. **Adding medium-high ventilation and reducing occupancy in a high-risk scenario.** • The median risk was reduced to 0.1% at the highest tracer concentration with medium-high ventilation and reduced occupancy. Further layering with surgical masks, despite reducing the relative risk by 98 ± 0.1%, did not bring the risk of transmission from a superspreader below the 0.1% threshold.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		inhalation deposition, incorporating tracer measurements into the model.		
			Numbers of air changes per hour (ACH) for optimal ventilation	
SARS-CoV-2 Alpha y Delta	Mizukoshi et al., 2023 (26) Japan	The study focused on analyzing a COVID-19 cluster within an office environment to understand the transmission pathways of the virus, particularly emphasizing the roles of long-range aerosol and fomite transmissions. **Methodology:** The study outlines a comprehensive methodology for assessing COVID-19 transmission risk in an office setting. It begins with the development of a model to simulate transmission pathways, focusing on aerosol and fomite transmissions, and assumes nine states in the pathway with calculated transition rates. The exposure dose is then assessed to understand the risk of onset and transmission. A sensitivity analysis is conducted to evaluate the impact of various parameters on transmission risk, including air virus concentration and infection control measures efficiency. The effectiveness of infection control practices, such as mask removal efficiency and air change rate, are evaluated. Finally, the spatial distribution of infected cases and the attack rate for each group in the office are	**Intervention:** Increasing the ACH to improve ventilation compared to a lower ACH rate, specifically one ACH, representing poor ventilation conditions. **Key outcomes:** Attack Rate	The interventions were analyzed for their impact on two transmission pathways: long-range aerosol transmission and fomite transmission. Ventilation effectiveness • Onset cases number resulting from long-range aerosol transmission increased to 29 and 21 when the air change rate was halved (0.5 ACH), decreased to 21 and 12 in case of doubled (2 ACH), and decreased to 16 and 6 in case of 6 ACH in the LF and SLF scenarios, respectively, when everyone wore masks with the removal efficiency of 60% for aerosols. • The risk reduction rate compared with the air change rate of 1 ACH was 12%–29% when the air change rate was doubled (2 ACH) and 36%–66% in cases of 6 ACH. The fomite transmission risk was considered not to be affected by the air change rate (the risk reduction rate was below 1%). • The relationship between the ACH and the number of onset cases depending on the mask removal efficiency was explored. The study found that increasing the ACH significantly reduced the number of cases due to long-range aerosol transmission, especially when combined with high-efficiency mask usage. Although specific numerical results for varying ACH levels are not provided in the cited text, the implication is that better-ventilated environments, when combined with effective mask usage, can lower the risk of COVID-19 transmission in office settings.

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		analyzed to understand cluster dynamics.		
SARS-CoV-2	Zand et al., 2023 (39) United States	The study aimed to assess the impact of ventilation and other mitigation measures on the spread of SARS-CoV-2 in a school setting specialized for individuals with intellectual and developmental disabilities (IDD). **Methodology:** The study's methodology involves analyzing CO_2 levels in school rooms and their correlation with room volume, ACH, and occupancy, as well as their impact on cognitive performance and relationship with ventilation systems and SARS-CoV-2 cases. The population studied includes students and staff within an IDD-specialized school, focusing on vulnerable populations under the NIH's RADx-UP program. The study evaluates various mitigation measures, including immunologic strategies, antiviral treatments, and isolation methods, with a specific emphasis on ventilation enhancement. It also details room characteristics such as HVAC systems and the use of MERV-13 filters in mitigating SARS-CoV-2 transmission. Lastly, the study uses the NonlinearModelFit function in Mathematica with the Levenberg-Marquardt algorithm	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: The study compared rooms with different levels of ACH, specifically aiming for an ACH of 4.0 or higher **Key outcomes:** SARS-CoV-2 infections Incidence	• The study found no statistically significant correlation between room ACH and per-room SARS-CoV-2 cases. This suggests that simply increasing ACH to the target level might not be sufficient on its own to significantly reduce the incidence of SARS-CoV-2 in this specific setting. (R2 =0.0036)
			Filters and filter ratings to use in a mechanical ventilation system	
			Intervention Use of MERV-13 Filters in HVAC Systems Comparator: The study compared rooms in buildings with HVAC systems equipped with MERV-13 filters against those with lower efficiency filters (MERV-11). **Key outcomes:** SARS-CoV-2 infections Incidence	• Rooms with ventilation systems using MERV-13 filters had lower SARS-CoV-2-positive PCR counts compared to those with MERV-11 filters. • The difference in PCR tests per room, normalized by room occupancy, between rooms with MERV-11 versus MERV-13 filters was statistically significant ($p < 0.0012$).

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		to estimate the room airflow needed to achieve 4 ACH based on room volume.		
SARS-CoV-2	Takahashi et al., 2023 (34)	The aim is to develop and demonstrate the effectiveness of the School Virus Infection Simulation-Model (SVISM) in evaluating the impact of different school schedules on the spread of virus infection at a school, with a focus on reducing the maximum number of students infected simultaneously and maintaining a certain rate of face-to-face lessons. **Methodology:** use of simulation models, specifically the School Virus Infection Simulation Model (SVISM), to evaluate the spread of COVID-19 in school settings. The study's experimental design: Testing the effects of changing classroom volumes and air change rates on the spread of the virus. Evaluating the impact of various school schedules on the maximum number of students infected simultaneously and the percentage of face-to-face lessons.	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Increasing classroom ventilation rates: 450 m3/h, 900 m3/h, 1350 m3/h, and 1800 m3/h. **Key Outcomes:** The maximum number of students infected simultaneously.	Numerical results are not reported in the description, only graphs. • The maximum number of students infected simultaneously decreased as the classroom ventilation rate increased. The variance of 450 m3/h results is the lowest among the variance of the lower classroom ventilation rates' results. These results show that increasing classroom ventilation effectively decreases the spread of COVID-19, and the impact of increasing classroom ventilation is not stable.
SARS-CoV-2	Xu et al., 2023 (36) United States	The paper investigates the trade-offs between indoor air temperature, Relative Humidity (RH), ventilation modes, energy consumption, infection risks, and	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Interventions: increased ventilation rate, implementation of air filtration, and maintaining	Numerical results are not reported in the description, only graphs.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		thermal comfort in U.S. schools during the COVID-19 pandemic. Through simulations and analysis, the study reveals the interconnected relationships among these factors and emphasizes the need for balancing them effectively to maintain a sustainable indoor environment. **Methodology:** The methodology employed in the study involves a comprehensive framework designed to analyze the trade-off between infection risk, energy consumption, and thermal comfort in U.S. schools during the COVID-19 pandemic. This framework is structured into three phases: preparation, simulation, and trade-off analysis. During the preparation phase, U.S. school data is collected, and building models are prepared with modifications for energy and thermal comfort simulation, considering the climate zone of each building. The simulation phase utilizes EnergyPlus for estimating building energy consumption and thermal comfort, and a revised Wells-Riley model for simulating indoor airborne infection risks. The trade-off analysis phase then compares the outcomes from the simulation models to understand	appropriate indoor air environment. **Key Outcomes:** Infection risk	• A linear relationship between air flow rate and infection risk was observed, as increased ventilation leads to the dilution of indoor air and a subsequent decrease in infection risk. • Ventilation rate governs the variations of infection risks and building energy usage, while indoor RH demonstrated negligible impacts.
			Environmental conditions to target for optimal ventilation	
			Interventions: increased ventilation rate, implementation of air filtration, and maintaining appropriate indoor air environment. **Key Outcomes:** Infection risk	Numerical results are not reported in the description, only graphs. • Key findings revealed that indoor temperature profoundly influences infection risk, energy consumption, and thermal comfort. Ventilation rate governs the variations of infection risks and building energy usage, while indoor RH demonstrated negligible impacts. Notably, thermal comfort and low infection risk can be concurrently realized, albeit at the expense of high energy consumption. • Comparing the optimal and worst environment settings in a typical U.S. climate zone, a 43% decrease in infection risks and a 61% increase in thermal comfort are observed, accompanied by an over 70% increase in energy consumption. The influences and trade-offs among infection risks, energy consumption, and thermal comfort are additionally modulated by climate characteristics.

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td>the relationships between the three aspects under study.</td><td></td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Feng et al., 2023(21)</td><td rowspan="2">The study aims to evaluate infection risk in urban public transport (UPT) systems, including buses, subways, and high-speed trains, based on factors such as ventilation rates, respiratory activities, and viral variants.

Methodology: A systematic approach is followed to assess the risks of COVID-19 transmission in various settings. Field measurements are collected by monitoring CO_2 concentrations and observing passenger behavior. The quanta emission rate generated by infected individuals is calculated, considering factors such as viral load and respiratory activity. Using the TJWR model, individual infection probabilities and room-scale risks are estimated, considering CO_2 levels, ventilation rates, mask leaks, and COVID-19 variants. Finally, non-vaccine control strategies are evaluated, such as improvements in ventilation, use of masks, social distancing, and reducing the frequency of conversation.</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>Key outcomes: Infection risk/ Reproduction number

<i>IRcp</i>01 individual's infection risk at the short-range scale (0–1 m) (%)
<i>IRcp</i>12 individual's infection risk at the short-range scale (1–2 m) (%)
<i>IRrs</i> individual's infection risk at the room-scale (%)
<i>Rcp</i>01 infection reproduction number at the short-range scale (0–1 m)
<i>Rcp</i>12 infection reproduction number at the short-range scale (1–2 m)
<i>Rrs</i> infection reproduction number at the room-scale</td><td>Reduction in Short-Range Infection Risk (IRcp01 and IRcp12)
• For short-range 1 (IRcp01), the decrease was by an average of 4% for buses, 2% for subways, and 3% for high-speed trains. For short-range 2 (IRcp12), the decrease was by an average of 7% for buses, 6% for subways, and 9% for high-speed trains.

Reduction in Room-Scale Infection Risk (IRrs):
• At the room-scale, increasing ACH led to an average decrease in IRrs by 55% for buses, 42% for subways, and 41% for high-speed trains.

<table>
<tr><th rowspan="3">Transport mode</th><th colspan="5">Infection Risk Assessments</th><th colspan="5">Influence of ACH on Infection Risk</th></tr>
<tr><th rowspan="2">Variant</th><th rowspan="2">Exposure Duration (h)</th><th colspan="3">Infection risk threshold (%)</th><th rowspan="2">IRcp01 (%)</th><th rowspan="2">IRcp12 (%)</th><th rowspan="2">IRrs (%)</th><th rowspan="2">Mitigation level <i>ACH</i> - by $5\ h^{-1}$</th><th rowspan="2">Total <i>R fold Compared to normal</i></th></tr>
<tr><th>IRcp01</th><th>IRcp12</th><th>IRrs</th></tr>
<tr><td rowspan="3">Buses:</td><td>Normal</td><td rowspan="3">0.2</td><td>7.1</td><td>4.2</td><td>0.78</td><td>4</td><td>7</td><td>55</td><td>1.6[1]
1.4[2]</td><td>0.8[1]</td></tr>
<tr><td>Delta</td><td rowspan="2">71.6[6]</td><td rowspan="2">40.8[6]</td><td rowspan="2">25.8[2]</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>3.8</td></tr>
<tr><td>Omicron</td><td>5.5</td></tr>
<tr><td rowspan="3">Subways:</td><td>Normal</td><td rowspan="3">0.2</td><td>6.3</td><td>3.4</td><td>0.23</td><td>2</td><td>6</td><td>42</td><td rowspan="3"></td><td>0.8[3]
0.6[5]</td></tr>
<tr><td>Delta</td><td rowspan="2">11.3[4]</td><td rowspan="2">19[4]</td><td rowspan="2">70.5[4]</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>3.2</td></tr>
<tr><td>Omicron</td><td>4.9</td></tr>
<tr><td rowspan="3">High-Speed Trains:</td><td>Normal</td><td rowspan="3">0.5</td><td>25</td><td>7.1</td><td>0.62</td><td>3</td><td>9</td><td>41</td><td>1.4[3]
0.6[1]</td><td>0.6[7]</td></tr>
<tr><td>Delta</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>3</td></tr>
<tr><td>Omicron</td><td>4.4</td></tr>
</table>
[1] higher than subways, [2] higher than high-speed trains, [3] lower than buses, [4] less than in buses, [5] lower than high-speed trains, [6] less than in high-speed trains, [7] lower than buses, ¯Reduction, -Increase

• Increasing the air change rate (ACH) in urban public transportation systems, particularly by opening windows, demonstrated a substantial potential for reducing infection transmission risks. Specifically, buses exhibited a notable capacity for reducing infection transmission risks when ACH was increased by $5\ h^{-1}$, showing a mitigation level 1.6-folds higher than subways and 1.4-folds higher than high-speed trains. However, increasing ventilation alone was not sufficient to prevent severe superspreading events (SSEs) in high-occupancy urban public transportation systems.</td></tr>
</table>

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
				Influence of Wearing Surgical Masks on Infection Risk: • The index case-wearing scenario resulted in an average reduction of IRrs by 81.6% for buses, 80.3% for subways, and 77.8% for high-speed trains. The both-wearing scenario showed a greater average mitigation effect, being 3.6-folds more effective than the index case-wearing scenario alone. **Ventilation Improvement:** Increasing ACH from the minimum to the maximum typical value. **Mask-Wearing Scenarios:** Index Case-Wearing Scenario: Only the index case wears a surgical mask. Both-Wearing Scenario: Both the index case and susceptible individuals wear a surgical mask.
			Numbers of air changes per hour (ACH) for optimal ventilation	
SARS-CoV-2	Pang et al., 2023 (29) United States	The aim of the study is to quantify the infection risk of COVID-19 under different ventilation scenarios and the consequent HVAC energy consumption, with the goal of guiding future building operation amid a pandemic of respiratory disease. **Methodology:** This study employs the Gammaitoni-Nucci model and EnergyPlus simulations to assess COVID-19 infection risk in office buildings. Key aspects include investigating the influence of outdoor air fractions on infection risk and HVAC energy consumption. The analysis considers parameters such as climate, zone type, occupancy density, exposure time, and outdoor airflow rates. Additionally, it examines the trade-offs between reducing infection risk and increasing	**Intervention:** Outdoor Air Fraction Increase: The primary intervention was the adjustment of outdoor air (OA) fraction from 30% to 100%, with increments of 10% for each scenario. This intervention was compared across 19 climate zones, leading to a total of 152 simulation scenarios. The comparator in this case was the baseline outdoor air fraction of 30%. **Key outcomes:** Infection Risk	Numerical results are not reported in the description, only graphs. • The simulation results demonstrated that increasing the outdoor airflow rate is an effective strategy to significantly reduce the COVID-19 infection risk across all climate zones. • Increasing the outdoor air fraction generally resulted in a reduction in COVID-19 infection risks. This outcome was consistent across different climates and seasons, demonstrating that higher air change rates (ACH), achieved through increased outdoor air intake, effectively reduce infection risks. • The probability of infection under different ventilation fraction scenarios and climate zones was also evaluated. The results indicated variability in the effectiveness of increased outdoor air fractions in reducing infection risks across different climates, underscoring the importance of climate-specific strategies for managing COVID-19 risk in office buildings. • The simulation results demonstrated that increasing the outdoor airflow rate is an effective strategy to significantly reduce the COVID-19 infection risk across all climate zones. • Outdoor Air Fraction Increase: The primary intervention was the adjustment of outdoor air (OA) fraction from 30% to 100%, with increments of 10% for each scenario. This intervention was compared across 19 climate zones, leading to a total of 152 simulation scenarios. The comparator in this case was the baseline outdoor air fraction of 30%. • Increasing the outdoor air fraction generally resulted in a reduction in COVID-19 infection risks. This outcome was consistent across different climates and seasons,

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		energy consumption. The study evaluates infection risk levels under various ventilation strategies.		demonstrating that higher air change rates (ACH), achieved through increased outdoor air intake, effectively reduce infection risks. • The probability of infection under different ventilation fraction scenarios and climate zones was also evaluated. The results indicated variability in the effectiveness of increased outdoor air fractions in reducing infection risks across different climates, underscoring the importance of climate-specific strategies for managing COVID-19 risk in office buildings.
SARS-CoV-2	Zafari et al., 2022 (38) United States	The study evaluated the cost-effectiveness of improving ventilation in commercial indoor spaces using standalone HEPA filtration units as a method of preventing the transmission of airborne SARS-CoV-2. **Methodology:** The modelling approach in this study is based on existing data and considers several critical factors, including airborne transmissibility, room geometry, temperature variations, and occupant movement. Notably, the study focused on airborne transmission through inhalation. While hospitalization and mortality rates were considered, they were modeled solely as a function of age, omitting other patient characteristics like gender, race, comorbidity, and socioeconomic status.	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: improving ventilation to 12 ACH **Key outcomes:** cost-effectiveness	It is cost-effective to improve indoor ventilation in small businesses in older buildings that lack HVAC systems during the pandemic. All 3 scenarios proposed in the study resulted in net cost-savings and infections averted. • For the base-case scenario, improving ventilation to 12 ACH was associated with 54 95% Credible Interval (CrI): 29–86 aerosol infections averted over 1 year, producing an estimated cost savings of $152,701 (95% CrI: $80,663–$249,501) and 1.35 (95% CrI: 0.72– 2.24) quality-adjusted life years (QALYs) gained. • For the best-case scenario improving ventilation to 12 ACH was associated with cost savings of $2,003 (95% CrI: − $881–$5968) and 0.05 (95% CrI: 0.03–0.09) QALYs gained. • For the worst-case scenario, improving ventilation to 12 ACH was associated with 135 (95% CrI: 76–213) infections averted, $455,277 (95% CrI: $247,879–$734,424) savings in costs, and 3.66 (95% CrI: 1.98– 6.02) increases in QALYs gained.
SARS-CoV-2	Yan et al., 2022 (37) Canada	The aim of the study is to evaluate the effectiveness of different mitigation strategies in reducing infection risk from a public health perspective in multizone, mechanically	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Doubling outdoor air ventilation. Increasing the outdoor air (OA) rate to 1.3BL, 2BL or 100% fresh air.	• Doubling outdoor air ventilation did not effectively reduce exposure risks unless 100% OA was applied. When the outdoor air percentage was adopted as 100%, the exposure risk was reduced to 1.12%, 40% down from the baseline case. • The relative reduction in risk achieved by increasing OA flow rates by 1.3 or 2 were minimal when compared to other strategies.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		ventilated buildings. The study also aims to validate the proposed CONTAM-quanta approach by comparing its results with those from previous studies.	**Key outcomes:** - R0 (basic reproduction number). - Relative reduction in infection risk.	• The acceptable risk level (R0 = 1) was calculated to be 0.75% for the 1st-floor Core Zone (nine-h exposures). For the baseline case, the exposure risk was estimated to be 1.83% without mask wearing. By increasing the OA rate to 1.3BL, 2BL or 100% fresh air, the exposure risk would drop to 1.79%, 1.66%, and 1.12%, respectively.
			Filters and filter ratings to use in a mechanical ventilation system	
		Methodology: Researchers adapted the Wells-Riley model to assess exposure to infectious "quanta" in multizone buildings. They quantified the relative benefits of different risk mitigation strategies, including increasing outdoor air ventilation rates and implementing air-cleaning devices such as MERV filters and PACs with HEPA filters, along with in-room/in-duct germicidal ultraviolet (GUV) lights. The case study focused on a large office prototype building from the US Department of Energy. By evaluating infectious risk propagation throughout the building, they compared the effectiveness of these strategies, both with and without universal masking, to minimize infection spread.	**Intervention:** The upgrade of the MERV-8 filter to a MERV-11 or MERV-13 **Key outcomes:** - R0 (basic reproduction number). - Relative reduction in infection risk.	• Results show that upgrading from MERV-8 to MERV-11 reduced individual exposure risks. For the baseline outdoor air ventilation scenarios, exposure risks fell by 29% for MERV-11 and 36% for MERV-13. • The upgrade of the MERV-8 filter to a MERV-11 or MERV-13 reduces the risk to 1.30% and 1.22%.
			Portable air cleaners	
			Intervention: PACs with recirculating airflow rates of 0.46 m3/s (PAC1, 0.71 ACH), 1 m3/s (PAC2, 1.55 ACH) and 1.45 m3/s (PAC3, 2.25 ACH) **Key outcomes:** R0 (basic reproduction number). Relative reduction in infection risk.	• The PAC evaluated in this study covered a large range of capacity, from 0.5 to 42.5 m3/s, which were based on the information provided by the industrial collaborator. These PACs were equipped with filters with an assumed single-pass efficiency of 99%. Among the investigated products, it was found that large capacity PACs (>17 m3/s) effectively lowered exposure risks below R0 < 1. • The use of PACs with recirculating airflow rates of 0.46 m3/s (PAC1, 0.71 ACH), 1 m3/s (PAC2, 1.55 ACH) and 1.45 m3/s (PAC3, 2.25 ACH) would reduce the exposure risks to 1.73%, 1.60% and 1.51%, respectively. The air cleaner with the highest flow rate of 17 m3/s (PAC4, 26.3 ACH) would help limit the risk to 0.51%, achieving an acceptable risk level (0.75%).
SARS-CoV-2	Barone, 2022 (16) Italy	The aim of the study was to investigate the energy, economic, and environmental feasibility of diverse ventilation strategies on railway coaches to reduce Covid-19 contagion risks.	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Reference System (RS) with an ACH of 18 vol/h and ARR of 80%. Proposed System 1 (PS1) with an ACH of 51 vol/h and ARR of 20%.	Scenarios with higher rates of outdoor air (PS1 and PS2) show a reduction in infection risk. Incorporating heat recovery (PS1.1 and PS2.1) maintains the reduced risk while potentially improving energy use. Covid-19 contagion risk probability (1 infectious passenger). **System** | **ACH** | **No mask** | **Surgical mask** | **N95 mask** | | **Probability of infection %**

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr>
<td></td>
<td></td>
<td>Methodology: Researchers developed a dynamic simulation tool within the OpenStudio environment to evaluate the performance of ventilation systems. They applied this tool to simulate a daily inter-regional train route between Naples and Rome, representing real-world operating conditions. They created a mathematical model using Matlab to assess the energy performance of the train and the probability of infection among passengers. Key considerations included outdoor airflow rates, filtration efficiency, and ventilation system design. By comparing various ventilation strategies, such as improving hourly air change (ACH) and reducing air recirculation rate (ARR) in railway coaches, they aimed to reduce Covid-19 infection risk. The study also accounted for varying passenger occupancy throughout the day, with a maximum occupancy assumed to be the number of seats plus 20% during rush hours.
The scenarios compared were:</td>
<td>Proposed System 1.1 (PS1.1) with an ACH of 51 vol/h and ARR of 0%.
Proposed System 2 (PS2) with an ACH of 51 vol/h and ARR of 40%.
Proposed System 2.1 (PS2.1) with an ACH of 51 vol/h and ARR of 20%.

Key outcomes: Covid-19 Infection Risk</td>
<td>
<table>
<tr><td>RS</td><td>18</td><td>2.38</td><td>0.84</td><td>0.02</td></tr>
<tr><td>PS2/PS1.2</td><td>31</td><td>1.42 (−40%)</td><td>0.50 (−40%)</td><td>0.01 (−50%)</td></tr>
<tr><td>PS1/PS1.1</td><td>51</td><td>0.88 (−63%)</td><td>0.31 (−63%)</td><td>0.01 (−50%)</td></tr>
</table>
<table>
<tr><td colspan="5">Covid-19 contagion risk probability (5 infectious passengers).</td></tr>
<tr><th rowspan="2">System</th><th rowspan="2">ACH</th><th>No mask</th><th>Surgical mask</th><th>N95 mask</th></tr>
<tr><th colspan="3">Probability of infection %</th></tr>
<tr><td>RS</td><td>18</td><td>11.35</td><td>4.13</td><td>0.12</td></tr>
<tr><td>PS2/PS1.2</td><td>31</td><td>6.91 (−39%)</td><td>2.48 (−39%)</td><td>0.07 (−42%)</td></tr>
<tr><td>PS1/PS1.1</td><td>51</td><td>4.32 (−62%)</td><td>1.53 (−63%)</td><td>0.04 (−66%)</td></tr>
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<tr>
<td rowspan="2">SARS-CoV-2</td>
<td rowspan="2">Ou & Luo, 2022 (28)

China</td>
<td rowspan="2">CFD was utilized to model airflows and investigate ventilation requirements of airborne transmission in a COVID-19 outbreak initiating with a 24-year-old man. Two buses (B1 and B2) were involved,</td>
<th colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</th>
</tr>
<tr>
<td>Key outcomes: Infection risk / attack rate</td>
<td>On both buses, the distribution of the exhaled tracer gas was rather uniform due to the airflow patterns.
Bus 1 (B1)
- Attack rate = 7/46, 15.2%
- Ventilation rate = 1.72 L/s per person 1.72 L/s per person</td>
</tr>
</table>

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		with 10 non-associated infected passengers. We collected epidemiological data, bus itineraries, the seating plans of passengers, and the details of the ventilation systems and operation, and we performed detailed ventilation and dispersion measurements on the two buses with the original drivers on the original route. Dates of symptom onset and the seating arrangements on the two buses were obtained, as well as interviews with drivers and passengers. Various combinations of air conditioning/heating and windows open/ closed were considered to simulate the airflow at the time of infection. The ventilation rates on the buses were measured using a tracer-concentration decay method with the original driver on the original route. We measured and calculated the spread of the exhaled virus-laden droplet tracer from the suspected index case.		- Exposure time = 200 minutes **Bus 2 (B2)** - Attack rate = 2/17, 11.8% - Ventilation rate = 3.22 L/s per person - Exposure time = 60 minutes The ventilation rate of a bus depended on the driving speed and extent of window opening. The difference in ventilation rates and exposure time could explain why B1 had a higher attack rate than B2. Airborne transmission due to poor ventilation below 3.2 L/s played a role in this two-bus outbreak of COVID-19.
SARS-CoV-2	Miller et al., 2022 (40)	The paper discusses a study that models the exposure of passengers to viruses, specifically SARS-CoV-2, in a subway train carriage through different routes such as close-range, long-range	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Different Fresh-flow air changes per hour [ACh−1]	Improved ventilation (high air change rate) is associated with a lower risk of transmission compared to poor ventilation (low air change rate). Enhancing ventilation within the subway carriages can significantly decrease the concentration of airborne virus particles, thereby reducing the risk of long-range airborne transmission. Total dose received by non-infectious passengers depending on ventilation rate

<table>
<thead>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
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<td>airborne, and fomite transmission. The results indicate that close-range exposure is the most dominant route, followed by fomite and long-range airborne routes. Factors like disease prevalence, passenger density, ventilation, and mitigation measures like social distancing and mask-wearing impact the exposure levels.

Methodology: The study employs a computational model named Transmission of Virus in Carriages (TVC) to simulate the exposure of passengers to SARS-CoV-2 in a subway train environment. The TVC model integrates numerous factors influencing virus transmission, including routes of exposure, behavioral and environmental factors and mitigation measures. The study varies parameters such as disease prevalence, ventilation rates, and mask-wearing compliance to analyze their impact on the exposure dose received by passengers.</td>
<td>Key Outcome: Total dose (virus) received by non-infectious passengers.</td>
<td>
<table>
<tr><th>Fresh-flow air changes per hour [ACh−1]</th><th>1</th><th>4</th><th>13</th><th>40</th><th>127</th></tr>
<tr><td>Median dose</td><td>1.17e−06</td><td>1.08e−06</td><td>7.33e−07</td><td>3.73e−07</td><td>1.46e−07</td></tr>
<tr><td>Mean dose</td><td>2.46e−03</td><td>2.35e−03</td><td>2.12e−03</td><td>1.72e−03</td><td>1.23e−03</td></tr>
</table>
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<tr>
<td rowspan="2">SARS-CoV-2</td>
<td rowspan="2">Arpino et al., 2022 (15)</td>
<td rowspan="2">The aim is to evaluate the risk of infection from SARS-CoV-2 Delta variant in a car cabin and to propose an integrated approach combining a predictive emission-to-risk approach and a validated CFD approach to design proper ventilation systems</td>
<td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td>
</tr>
<tr>
<td>Interventions: Different HVAC system flow rates (10%, 25%, 50%, 75%, and 100%)
Three different HVAC ventilation modes: mixed, front, and windshield</td>
<td>Influence of the HVAC System Flow Rate Interventions: the study found that varying the HVAC system flow rate significantly influences the inhaled dose of airborne respiratory particles and the corresponding infection risk for the occupants. Specifically, higher flow rates were associated with reduced inhaled doses and lower infection risks, demonstrating the effectiveness of increased ventilation in mitigating airborne transmission risk within the car cabin.

<table>
<tr><td>HVAC</td><td>Individual infection risk (%)-All Passengers</td></tr>
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<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3">for car cabins. The study aims to understand the influence of key parameters such as HVAC flow rate, ventilation mode, position of the infected subject, and expiratory activity on the risk of infection.

Methodology: The study employed a comprehensive methodology combining Computational Fluid Dynamics (CFD) simulations and a predictive emission-to-risk approach to evaluate the risk of SARS-CoV-2 Delta variant infection within car cabins. The study estimated the dose of viral load received by susceptible individuals and assessed the probability of infection based on this viral load. It also considered the probability of secondary transmission by considering the number of susceptible occupants in the car.
Passenger 1: c
-pilot
Passenger 2: sitting behind the pilot.
Passenger 3 Sitting behind the co-pilot.</td><td>defrosting, all at a 50% flow rate.

Key outcomes: infection risk</td><td>
<table>
<tr><td>airflow ratio</td><td colspan="3"></td><td></td></tr>
<tr><td>Q100%</td><td>Passenger #1</td><td>Passenger #2</td><td>Passenger #3</td><td>All Passengers</td></tr>
<tr><td>Q100%</td><td>0</td><td>0.76%</td><td>2.9%</td><td>35%</td></tr>
<tr><td>Q75%</td><td>0.03%</td><td>0.46%</td><td>2.0%</td><td>38%</td></tr>
<tr><td>Q50%</td><td>9.2%</td><td>26%</td><td>18%</td><td>42%</td></tr>
<tr><td>Q25%</td><td>36%</td><td>8.3%</td><td>7.2%</td><td>48%</td></tr>
<tr><td>Q10%</td><td>51%</td><td>53%</td><td>32%</td><td>55%</td></tr>
</table>
</td></tr>
<tr><td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td></tr>
<tr><td>Interventions:
Different HVAC system flow rates (10%, 25%, 50%, 75%, and 100%)
Three different HVAC ventilation modes: mixed, front, and windshield defrosting, all at a 50% flow rate.

Key outcomes: infection risk</td><td>Influence of the HVAC Ventilation Mode Interventions: The study highlighted significant differences in the risk of infection among the ventilation modes. The well-mixed solution indicated that the windshield defrosting mode provided a reasonable approximation of the CFD results, suggesting it might be more effective in reducing infection risk compared to the front ventilation mode, which was the least effective in mixing the air within the cabin, thereby significantly overestimating the risk for back seat passengers.

<table>
<tr><td rowspan="3">HVAC ventilation mode</td><td colspan="4">Individual infection risk (%)</td></tr>
<tr><td>Passenger #1</td><td>Passenger #2</td><td>Passenger #3</td><td>All Passengers</td></tr>
<tr><td>CFD</td><td>CFD</td><td>CFD</td><td>Well-mixed</td></tr>
<tr><td>Front mode</td><td>53%</td><td>0.17%</td><td>0.06%</td><td>42%</td></tr>
<tr><td>Windshield defrosting mode</td><td>32%</td><td>59%</td><td>22%</td><td></td></tr>
<tr><td>Mixed mode</td><td>9.2%</td><td>26%</td><td>18%</td><td></td></tr>
</table>
</td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Farthing & Lanzas, 2021 (20)

United States</td><td rowspan="2">The objective of the study was to evaluate non-pharmaceutical interventions to reduce indoor SARS-CoV-2 transmission during superspreading events.</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>Key outcomes: SARS-CoV-2 transmission risk (Logit scale estimates associated with 1-unit increases in covariate values)</td><td>Ventilation and Airflow:
The study considered the role of ventilation and airflow, including forced air direction and air change rates, with comparators being scenarios with less optimal airflow conditions.</td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td>**Methodology:** Researchers developed a spatially explicit agent-based model (ABM) to simulate indoor respiratory pathogen transmission, with a focus on SARS-CoV-2. The model compared the effects of four interventions: avoiding movement within the room, wearing masks, social distancing, and ventilation airflow. Using a case study based on a probable superspreading event in Skagit County, Washington, USA, they conducted 1,080,000 simulations to test parameters and intervention.</td><td></td><td>Though filtering re-circulated air can lower transmission risk, increasing this effect is unlikely to compensate for the elevated risk attributable to increased horizontal air-change rates.
<table>
<tr><td colspan="4">Logit scale estimates associated with 1-unit increases in covariate values given by the logistic-regression model for evaluating effect on SARS-CoV-2 transmission risk during an indoor gathering. Wald 95% confidence intervals are given in parentheses.</td></tr>
<tr><th>Coefficient</th><th>β Estimate</th><th>Odds ratio</th><th>p</th></tr>
<tr><td>Air change rate (%/min)</td><td>0.017 (0.017, 0.017)</td><td>1.02 (1.02, 1.02)</td><td>< 0.001</td></tr>
<tr><td>Air filtration rate (%/min)</td><td>-0.005 (−0.005, −0.005)</td><td>0.995 (0.995, 0.995)</td><td>< 0.001</td></tr>
</table>

Authors concluded that there is potential for ventilation airflow to expose susceptible people to aerosolized pathogens even if they are relatively far from infectious individuals. Maximizing the vertical aerosol removal rate is paramount to successful transmission-risk reduction when using ventilation systems as intervention tools.</td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Pease et al., 2021 (30)

United States</td><td rowspan="2">The study aims to explore the impact of aerosolized spread of SARS-CoV-2 via air handling systems within multiroom buildings and to provide insights into the effectiveness of interventions such as filtration, air change rates, and the fraction of outdoor air in reducing the risk of virus spreading between rooms connected by an air handling unit.

Methodology: Researchers evaluated aerosolized viral spread within a multiroom building connected through a central air handling system. They derived equations and parameters to assess the influence of filtration,</td><th colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</th></tr>
<tr><td>**Key outcomes:** Infection probability</td><td>**Outdoor Air Introduction:**
• Increasing the amount of outdoor air reduces the peak concentration of particles in connected rooms.
• The decrease is meaningful, and the difference between no outdoor air and 33% outdoor air is less than a factor of two.
• Interestingly, this reduction is smaller than the difference between MERV-8 and MERV-11 filters, suggesting that increasing filtration efficiency may be more effective than increasing outdoor air fraction.
• When the fraction of outdoor air is increased from 0% to 33%, the risk of infection decreases from 0.22% to 0.16%.
• However, due to its significant impact on energy use and thermal comfort, ventilation should be increased thoughtfully in heating- or cooling-dominated climate zones.

Source Room Air Flow Rate:
• Increasing the air flow rate in the source room decreases the probability of infection.
• Even with a MERV-8 filter and low air change rates, the probability of infection is around 8%.</td></tr>
</table>

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		air change rates, and outdoor air fraction on infection probability using a well-mixed modelling approach. Additionally, they investigated contaminant source locations (both indoor and outdoor) and their effects on aerosol concentration. The study also analyzed the air handling system's role, including mixing outdoor and return air, filtering it with MERV-rated filters, and delivering it to individual rooms.		• At the highest air change rate considered (12 ACH), the probability of infection drops to approximately 2% in the source room. • Caution is needed when increasing the air change rate, as it may also increase the rate of viral particles spread via HVAC systems. • Specifically, when the ACH is increased from 1.8 to 12, the time to peak virus concentration in connected rooms decreases from 30 minutes to 11 minutes. • Higher ACH decreases the concentration in the source room. However, it leads to an increased peak concentration in connected rooms due to more flow from the source room. • Balancing these effects is crucial for effective infection risk reduction. In summary, outdoor air introduction and optimizing air flow rates play key roles in minimizing aerosol transmission via HVAC systems.
			Filters and filter ratings to use in a mechanical ventilation system	
			Intervention: Implementation of MERV-8, MERV-11, and MERV-13 filters. **Key outcomes:** Infection probability	• With filtration, the probability of infection in the source room is attenuated by a percent or two. In the connected rooms, filtration with a MERV-8 filter lowers the risk by almost an order of magnitude and a MERV-13 filter further lowers the risk of infection by another order of magnitude. Even so, there is still a risk of only one in ~7300 with a MERV-13 filter in the connected room, the lowest probability of infection for any of the cases considered here. • For typical levels of recirculation, filtration is most effective in lowering the particles concentration and probability of infection via HVAC systems as filters block the path of viral particles. For example, MERV-8 filters reduce the risk of infection from 1.5% (no filter) to 0.2% in the connected rooms. In theory, higher filtration level(s) result in higher level(s) of protection. However, the risks of infection are all relatively small beyond MERV-8 (e.g., 0.04% and 0.01% risks of infection for MERV-11 and MERV-13, respectively). • MERV-8 filters reduced the risk of infection from 1.5% (no filter) to 0.2%. Higher filtration levels (MERV-11 and MERV-13) further reduced the risk to 0.04% and 0.01%, respectively. This indicates that filtration is the most effective method in lowering particles concentration and probability of infection via HVAC systems.
SARS-CoV-2	Cotman et al., 2021 (19) United States	The aim of the study was to evaluate the effectiveness of HVAC systems in reducing the transmission of SARS-CoV-2 in indoor environments, including multistory office buildings and social gathering settings such as	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Increasing ACH: This intervention involved enhancing the ventilation rate within the office environment.	**Increasing ACH:** Increasing ACH significantly reduced the transmission of SARS-CoV-2 in indoor environments, making it the most effective mitigation measure compared to baseline HVAC settings. (Office scenario, $P < 0.05$; Social gatherings, $P < 0.05$). **Office scenario results:**

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		bar/restaurants, nightclubs, and wedding venues. **Methodology:** Researchers employed a simulation model to evaluate the impact of HVAC parameters on viral transmission. Their focus was on estimating aerosol decay rates for SARS-CoV-2 or simulated droplets across different particle sizes, specifically in the 1–10-micron range. The model incorporated parameters such as ACH, filter efficiency, ultraviolet light decontamination, and portable filtration units. It comprehensively modeled particle generation, settling, bi-directional mixing, filtration, ventilation, and biological decay. By simulating population movement and dose-response, they calculated infection probabilities. The study assessed infection risk reduction strategies, including increasing ACH, improving filter efficiency, adjusting FOA, and implementing UV decontamination and in-room filtration. The model's validity was confirmed through simulations of symptomatic aerosol release in a residential setting.	Increasing the FOA: This strategy entailed increasing the proportion of outside air mixed into the building's ventilation system. **Key outcomes:** Infection risk reduction	from 2 to 6, results in 28% fewer infections (from 0.0081% to 0.0058%) from 6 to 10 results in 15% fewer infections (from 0.0058 to 0.0049) from 10 to 20 results in 34% fewer infections (from 0.0049 to 0.0032) from 20 to 30 results in 29% fewer infections (from 0.0032 to 0.0022) **Social gathering scenario results:** **Increasing the FOA:** Enhancing the FOA in HVAC systems contributed to a decrease in virus transmission, showing effectiveness as a mitigation measure but with diminishing returns compared to increasing ACH. (Office scenario, P = 0.03; Social gatherings, P = 0.04). **Low Fresh Outdoor Air (FOA) Intake**: A low FOA intake was associated with increased disease prevalence, highlighting the importance of sufficient outdoor air intake in reducing SARS-CoV-2 transmission. (P = 0.02).
			Filters and filter ratings to use in a mechanical ventilation system	

Increasing ACH and the FOA reduce simulated SARS-CoV-2 infections in the bar/restaurant, wedding reception venue, and nightclub with an emission rate of 3,000 PFU / min.

Building air circulation			**FOA**		
ACH	Fraction Infected	% Change	FOA	Fraction Infected	% Change
Bar					
2	0.220	305	0.1	0.093	70
6	0.113	108	0.299*	0.054	0
10	0.063	16	0.3	0.053	-4
11*	0.054	0	0.5	0.036	-35
20	0.019	-65	0.9	0.022	-60
30	0.007	-87			
Wedding					
2	0.1347	20	0.1	0.150	34
2.5*	0.112	0	0.299*	0.112	0
6	0.0350	-69	0.3	0.111	-1
10	0.0125	-89	0.5	0.089	-21
20	0.0019	-98	0.9	0.066	-41
30	0.0005	-100			
Nightclub					
2	0.0932	3,763	0.1	0.0073	202
6	0.0302	1,152	0.299*	0.0024	0
10	0.0124	412	0.3	0.0022	-8
19.8*	0.0024	0	0.5	0.0015	-40
20	0.0024	-2	0.9	0.0010	-58

*Values for typical social gathering settings used as baseline for illustration

<table>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Intervention:
Increasing Filter Efficiency (MERV rating): This involved upgrading the HVAC system with filters of higher Minimum Efficiency Reporting

Key outcomes: Infection risk reduction</td>
<td>Increasing MERV rating
Office scenario results:
from 4 to 8 results in 8% fewer infections (from 0.0060 to 0.0055),
from 8 to 12, results in 5% fewer infections (from 0.0055 to 0.0052)
from 12 to 16, showed no difference.

Social gathering scenario results:
<table>
<tr><td colspan="3">Increasing filter MERV rating reduce simulated SARS-CoV-2 infections in the bar/restaurant, wedding reception venue, and nightclub with an emission rate of 3,000 PFU / min.</td></tr>
<tr><td>MERV</td><td>Fraction Infected</td><td>% Change</td></tr>
<tr><td colspan="3">Bar</td></tr>
<tr><td>MERV-4</td><td>0.088</td><td>6</td></tr>
<tr><td>MERV-8*</td><td>0.054</td><td>0</td></tr>
<tr><td>MERV-12</td><td>0.024</td><td>-57</td></tr>
<tr><td>MERV-16</td><td>0.021</td><td>-61</td></tr>
<tr><td>UVC**</td><td>0.021</td><td>-61</td></tr>
<tr><td colspan="3">Wedding</td></tr>
<tr><td>MERV-4</td><td>0.153</td><td>36</td></tr>
<tr><td>MERV-8*</td><td>0.112</td><td>0</td></tr>
<tr><td>MERV-12</td><td>0.069</td><td>-38</td></tr>
<tr><td>MERV-16</td><td>0.065</td><td>-42</td></tr>
<tr><td>UVC**</td><td>0.065</td><td>-42</td></tr>
<tr><td colspan="3">Nightclub</td></tr>
<tr><td>MERV-4</td><td>0.0045</td><td>85</td></tr>
<tr><td>MERV-8*</td><td>0.0024</td><td>0</td></tr>
<tr><td>MERV-12</td><td>0.0010</td><td>-57</td></tr>
<tr><td>MERV-16</td><td>0.0010</td><td>-59</td></tr>
<tr><td>UVC**</td><td>0.0010</td><td>-59</td></tr>
<tr><td colspan="3">*Values for typical social gathering settings used as baseline for illustration</td></tr>
<tr><td colspan="3">** UVC filtration of 90% and 99% efficiency with any mechanical (MERV-rated) filter produced similar results.</td></tr>
</table>

Ultraviolet Light (UVC) Decontamination:
The application of UVC decontamination within HVAC systems effectively reduced SARS-CoV-2 transmission, demonstrating comparable efficacy to high-efficiency mechanical filtration. (Office scenario, P = 0.005; Social gatherings, P = 0.007).

In-room Filtration Units:</td>
</tr>
</table>

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
				Utilizing in-room filtration units contributed to a reduction in the transmission of SARS-CoV-2, indicating their effectiveness as an additional mitigation strategy alongside other HVAC improvements. (Office scenario, P = 0.008; Social gatherings, P = 0.009).
			Combinations of ventilation and filtration strategies	
			Intervention: Increasing ACH, Increasing Filter Efficiency (MERV rating), Increasing the FOA. The study evaluated the efficacy of HVAC systems in mitigating SARS-CoV-2 transmission during social gatherings in single-story buildings with limited compartmentalization, such as: Bar/Restaurant Nightclub Wedding Reception Comparators: The comparators for these scenarios would be the same types of events without enhanced HVAC mitigation strategies, implying standard ventilation, filtration, and outside air mixing practices. **Key outcomes:** Infection risk reduction	**Combined HVAC Interventions:** Implementing a combination of increased ACH, higher filter efficiency, and enhanced FOA significantly reduced SARS-CoV-2 transmission rates more effectively than any single intervention alone. (Office scenario, P < 0.001; Social gatherings, P < 0.001).
SARS-CoV-2	Aganovic et al., 2021 (14) Norway	The study aimed to provide insights into the effectiveness of Relative Humidity (RH) and ventilation in controlling the	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: The study contrasts a low ventilation rate (0.5 h^{-1})	**Increasing the ACH from 0.5 to 2 and 6 ACH.** • Increasing the ventilation rate from 0.5 ACH to 6 ACH significantly decreased the infection risk by up to 54% for droplets smaller than 5 μm in diameter at a

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		virus concentration in the air, allowing for informed decisions concerning indoor environmental control. The study used a modelling approach to assess the infection risk of airborne transmission of SARS-CoV-2 in confined spaces, incorporating the impact of RH on the volume emission of respiratory droplets from an infected individual and its removal mechanisms of deposition by gravitational settling and inactivation by biological decay. **Methodology:** The proposed methodology involves developing a predictive model to estimate indoor SARS-CoV-2 quanta concentrations and infection risk. It incorporates the impact of RH on volume emission of respiratory droplets, deposition, and viral inactivation mechanisms. Key considerations include viral emission rate, deposition rate, virus inactivation rate, viral load, droplet size distribution, and RH's effect on virus survival and droplet evaporation. The study also simulates classroom scenarios to assess the impact of ventilation rates and humidity levels on infection risk. Finally, a modified Wells-Riley model is utilized to compare the effects of	with a high ventilation rate (6 h^{-1}), under conditions of varying RH. **Key outcomes:** Infection Risk	constant RH. This intervention highlights ventilation as the dominant removal mechanism for small infectious respiratory droplets, which can remain suspended in the air over long distances and for extended periods.
			Environmental conditions to target for optimal ventilation	
			Intervention: Modifying indoor RH levels to 20%, 37%, 53%, 70%, and 83.5%. **Key outcomes:** Infection Risk	**Modifying indoor RH levels to 20%, 37%, 53%, 70%, and 83.5%.** The modelling performed assumed continuous talking by an infected person for durations of 60 and 120 minutes. • The modification of indoor RH levels, specifically humidification to moderate levels of 40% – 60% RH, was not found to provide a significant reduction in infection risk caused by SARS-CoV-2 compared against the removal achieved by increased ventilation rate with outdoor air. • The results indicated that the impact of RH on infection risk was dependent on the ventilation rate and the size range of the virus-laden droplets. At a low ventilation rate of 0.5 ACH, changing RH between 20% and 53% had a small effect on infection risk. However, at a higher ventilation rate of 6 ACH, the change in RH had nearly no effect on infection risk. The results indicate that increasing the ventilation rate is more effective for reducing the airborne levels of SARS-CoV-2 than changing indoor RH.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		ventilation and RH on airborne transmission risk.		
SARS-CoV-2	Xu et al., 2021 (12) United States	The aim of the study is to evaluate the effectiveness of different intervention strategies, including increased ventilation, air filtration, and hybrid learning, in reducing the airborne infection risk of SARS-CoV-2 in U.S. public and private schools under different epidemiological scenarios. **Methodology:** The study involves a comprehensive scenario-based analysis of 111,485 U.S. public and private schools during the COVID-19 pandemic. It predicts both long- and short-term infection risks under various intervention strategies. To explore the impact of school characteristics and epidemic situations, the study employs Monte Carlo simulation and sensitivity analysis. Furthermore, it evaluates the effectiveness of interventions such as increased ventilation, MERV-13 filters, and hybrid learning. The study assesses combined strategies aimed at reducing infection risk in school settings.	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Intervention S1: Increasing the Ventilation Rate by 100% Comparator: Baseline ventilation rate without enhancement. **Key outcomes:** Infection Risk	**Increasing the Ventilation Rate by 100% (S1):** • Doubling the ventilation rate is effective in reducing infection risk, though its impact is less significant compared to the implementation of MERV-13 filters. The effectiveness of this strategy is comparable to that of hybrid learning but falls short of the significant risk reduction achieved by MERV -13 filters. This strategy, while beneficial, may not be sufficient on its own to maintain infection risk below desired thresholds in all scenarios.
			Filters and filter ratings to use in a mechanical ventilation system	
			Intervention: Intervention S2: Implementing MERV-13 Filters Comparator: Baseline scenario without MERV-13 filtration. **Key outcomes:** Infection Risk	**Implementing MERV-13 Filters:** • Implementing air filtration strategies, specifically through the use of MERV-13 filters, significantly reduces the SARS-CoV-2 airborne infection risk in schools compared to baseline scenarios. • This intervention alone can maintain infection risks below the 1% threshold in pre-kindergarten settings throughout the year. • In contrast, increasing the ventilation rate by 100% and adopting hybrid learning models offer less risk reduction, with air filtration proving over 30% more effective than these methods.
			Combinations of ventilation and filtration strategies	
			Intervention: Combined Strategies: S4 (S1 + S2): Increasing the Ventilation Rate and Implementing MERV-13 Filters S5 (S1 + S3): Increasing the Ventilation Rate and Hybrid Learning S6 (S1 + S2 + S3): Increasing the Ventilation Rate, Implementing MERV-13 Filters, and	**Combined Interventions (S4, S5, S6):** • The combination of increasing the ventilation rate and implementing MERV-13 filters (S4), as well as the combination of these strategies with hybrid learning (S6), effectively keeps the infection risk below 1% throughout the year for elementary and combined schools. The effects of S4 and S5 (increasing the ventilation rate and switching part of the student body to online learning) are almost the same. • The combination of increased ventilation and MERV-13 filters, with or without hybrid learning, effectively keeps infection risks below 1% across elementary and combined schools.

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
			Hybrid Learning Comparators: Each combined strategy was compared against the baseline scenario and each other. **Key outcomes:** Infection Risk	
SARS-CoV-2	Shen et al., 2021 (33) United States	The paper evaluates various control strategies such as ventilation, air filtration, and mask-wearing at different scales to reduce infection risks. **Methodology:** The methodology employed in this study aims to estimate infection probabilities and basic reproduction numbers (R0) for various indoor spaces and scenarios. Key components include utilizing the Wells-Riley Model to estimate infection probabilities through airborne transmission, analyzing the effectiveness of Indoor Air Quality (IAQ) control strategies (such as ventilation improvement, filter upgrades, air cleaners, and masks), evaluating different spaces (e.g., long-term care facilities, educational settings) and scenarios (ventilation systems, masks, occupancy) using a stochastic Monte Carlo approach, and considering key parameters such as the infectious quantum	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Increase outside air (OA) in the ventilation system. Increasing the total supply airflow rate. **Key outcomes:** R0	• The ventilation system with more outdoor air can reduce infection risk. An average risk reduction of 27% can be achieved when using 100% OA. • Increasing the total supply airflow rate can reduce considerable infection risk as well. Doubling the total supply airflow rate can reduce around 37% risk in average. Doubling the total supply airflow rate can reduce around 37% risk in average.
			HVAC systems (e.g. displacement, mixing systems)	
			Intervention: Displacement ventilation **Key outcomes:** R0	• Room air distributions can impact the infection risk. DV can reduce average 26% infection risk, while installing partitions can reduce around 46% risk.
			Filters and filter ratings to use in a mechanical ventilation system	
			Intervention: Implementation of HEPA filters in the ventilation system **Key outcomes:** R0	• A higher-efficiency filter in the ventilation system can supply more cleaned air. A HEPA filter can reduce equivalent infection risk to the strategy applying 100% outdoor air. Graphs only, no tables or full description of results
			Portable air cleaners	
			Intervention: Implementation of Personal ventilation **Key outcomes**: R0	• Personal ventilation (PV) can further reduce the risk of infection, on average by 67%. • The impacts of the standalone air cleaning technologies vary greatly in various spaces, from below 10% risk reduction to over 85%. The average risk reduction for air cleaners is around 31%. The impacts of the standalone air cleaning technologies vary in various spaces, from below 10% risk reduction to over 85%. The average risk reduction for air cleaners is around 31%.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		generation rate, size distribution of infectious particles, pulmonary ventilation rate, filter and mask efficiency, and particle deposition and inactivation rate.		
SARS-CoV-2	Mokhtari & Jahangir, 2021 (27) Iran	The aim was to investigate the impacts of occupant distribution patterns, air exchange rate, working hours, and class duration on HVAC system's energy consumption and the number of infected people with COVID-19 in a university building. **Methodology:** the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) was utilized to optimize occupant distribution patterns within the building. The study incorporated energy simulation, thermal comfort analysis, and COVID-19 infection risk assessment as part of the optimization process. The optimization process considered numerous factors such as air exchange rate, working hours, class duration, and the distribution of occupants. These factors were analyzed for their impact on both the risk of infection and energy consumption.	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: many air exchange rate (AER) values were considered for the building **Key outcomes:** number of infected people with COVID-19 in the building	• As the AER increases, the number of infected people with the virus decreases exponentially, but the building energy consumption also increases. • The AER value of 2.8 hr^{-1} is obtained as the optimum value where two objective functions meet and can be introduced as the balance point for the building.
SARS-CoV-2	Gao et al., 2021 (22)	The aim of the study is to develop a comprehensive mathematical model to evaluate the contributions of different	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: Increasing Ventilation Rates	• In the long-range airborne transmission dominant scenario (face-to-face exposure time ti, j = 0.5), with the increase of the air change rate from 0.25 (18.75 m3/h) to

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		transmission routes in respiratory infections, using a theoretical simulation framework. **Methodology:** This study presents a mathematical model that examines the relative contributions of various transmission routes in respiratory infections, including long-range airborne transmission, short-range airborne transmission, direct inhalation of droplets, direct deposition of droplets, and contact transmission. The model challenges the traditional dichotomy of close contact versus airborne transmission by illustrating scenarios where each route may dominate. By evaluating factors like ventilation rates, dose-response coefficients, and viral dilution rates, the study aims to provide a comprehensive method for assessing infection risk and predicting the impact of intervention strategies in indoor environments.	**Key outcomes:** Infection risk	10 ACH, the total infection risk decreases by ~40% (85% reduction in infection risk from the long-range airborne route). Authors concluded that higher ventilation rates significantly reduce the contribution of long-range airborne transmission to the total infection risk. This suggests that improving ventilation can be a critical intervention in indoor environments to reduce the spread of infections transmitted through the air over longer distances.
SARS-CoV-2	Schibuola & Tambani, 2021 (32) Italy	The aim of the study is to investigate the possibility of reducing airborne contagion by a strong increment of ventilation rates in indoor environments, particularly in school classrooms, and to improve energy recovery in ventilation systems to address the new ventilation requirements	**Numbers of air changes per hour (ACH) for optimal ventilation** **Intervention:** increasing ventilation rates in indoor environments, with specific consideration for different ventilation rates based on occupancy and the installation of an autonomous high efficiency air handling unit (HEAHU) in existing	• High ventilation rates, facilitated by innovative ventilation systems, can effectively reduce viral concentration and infection risk, making indoor spaces safer. • The installation of autonomous high efficiency ventilation units, like HEAHU, offers a sustainable solution to improve indoor air quality and reduce energy consumption in school environments during the COVID-19 pandemic. • The HEAHU could drastically reduce the quantity of contaminants (QC(t)) and consequently the risk of contagion (R(t)), making high ventilation rates feasible and effective even when using facemasks with acceptable filtration levels in school environments.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		characterized by elevated flow rates. **Methodology:** The study involves analyzing emission rates of respiratory droplets in indoor settings, considering the influence of physical activities on viral load concentration. It quantifies infection risk using mathematical models based on viral dose inhalation, allowing for assessment of various scenarios and interventions. Additionally, the study monitors CO_2 concentrations and ventilation rates in classrooms to assess indoor air quality. Simulations explore the effects of increased mechanical ventilation rates on infection risk, considering filtration efficiencies. Finally, a proposed High Efficiency Air Handling Unit (HEAHU) based on heat pump technology aims to enhance energy efficiency while increasing ventilation rates, with validation using monitoring data from schools in Italy.	naturally ventilated classrooms. **Key outcomes:** Infection Risk	• The final R0 could be reduced below 1, a condition considered safe for public activities by health authorities. Moreover, the energy performance simulation of the HEAHU demonstrated its capability to significantly contain energy consumption despite the increased ventilation rates. • The simulation showed that increasing mechanical ventilation rates significantly reduced the risk of contagion (R(t)) and the basic reproduction number (R0). Specifically, with an average filtration efficiency of 50%, R0 was reduced to 0.9 with a ventilation rate of 32 l/s per person. With a 75% filtration efficiency, R0 dropped below 1 (indicative of a decrease in contagion risk) with just 16 l/s per person, reaching 0.45 with 32 l/s per person.
SARS-CoV-2	Vernez, et al., 2021 (35) Switzerland	Investigation of an outbreak in a courtroom in Vaud state of Switzerland, October 30, 2020. Ten people participated in hearing in the same courtroom. Without considering the index case, 4 of the 9 people present became infected within days of the hearing. For one of the cases, it was deemed that infection	**Numbers of air changes per hour (ACH) for optimal ventilation** **Key outcomes:** Probability of infection	• Results presented graphically; probability of infection lower with higher ventilation rates when duration of event was 1.5 and 3 hours; slight difference in probability of infection across different ventilation rates when event duration was 0.5 hours. Authors concluded that while room ventilation is essential, it is difficult to control risk of contamination with this parameter alone because of the residual probability of infection at high ventilation rates, brought by the variability of the other parameters (e.g., duration of exposure and emission rate)

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		most likely came from another source. Field investigation of outbreak with ventilation system not working and single window and all doors closed, except for window being open during breaks (masking and social distancing requirements were in effect). Estimated air renewal rate of 0.23 h^{-1} Modelling to estimate probability of infection under different conditions including ventilation rate, emission rate, and duration of exposure. Simulation with variable air exchange rates, ranging from 0 to 5 h^{-1}. Assumed secondary attack rate of 33-44% (3-4/9).		
SARS-CoV-2	Li et al., 2020 (23) China	Simulation experiments in dormitory buildings according to original conditions when two COVID-19 outbreaks occurred. Epidemiological data were collected, and ventilation conditions (doors/windows open and operation of ventilation equipment) were investigated at time of occurrence. Data was collected about date of symptom onset, mask wearing, number infected and their distributions. Ventilation rate was measured by	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Key outcomes: Infection rate	**Hubei M Zone:** ventilation rate = 236 m3/h, average per person was 7.7 m3/h**;** infection rate = 8% **Hubei N Zone:** ventilation rate = 601 m3/h, average per person was 28 m3/h; Infection rate = 16% -Zone M had lower infection rate with worse ventilation levels, which was attributed to mask wearing. **Shandong:** ventilation rate = 178 m3/h, average per person was 21 m3/h**;** infection rate = 74% -Difference in infection rates between Shandong and Hubei attributed to mask wearing habits. -Data from Zone N in Hubei showed a threshold of ventilation rate. When the room ventilation rate was > 800 m3/h or 40 m3/h per person, rate of infection was <25%. When room ventilation rate was < 800 m3/h or 40 m3/h per person, the highest infection rate reached 56%.

<table>
<thead>
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</thead>
<tbody>
<tr><td></td><td></td><td>CO_2 tracer concentration decay method.

The <i>Shandong Province</i> dormitory was mainly mechanically ventilated with 30 rooms averaging 9 residents/room. Transmission period Jan 21 to Feb 12, 2020. Calculated infection was between 29–100%, of which 7 rooms had a 100% rate of infection. During outbreak interior doors were open and exterior windows closed, no masks.

The dormitory in <i>Hubei province</i> had no mechanical ventilation, with 90 rooms averaging 21 residents/room. Outbreak between January 21 to February 11, 2020. Zone M had older residents with door and windows closed and wore masks day and night. Zone N had young and middle-aged residents, did not wear masks at night and opened windows all day. Calculated infection rate was between 0% and 56%, of which 14 rooms had a 0% rate of infection.</td><td></td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Liu et al., 2020 (24)

United States</td><td rowspan="2">CFD-based investigation of indoor air flow and the associated aerosol transport in a restaurant setting (Guangzhou, China; January 2020), where likely cases of airborne infection of COVID-19 caused by asymptomatic individuals were</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>Key outcomes: Infection risk</td><td>• In simulation with increased ventilation, the risk of infection is decreased (Fig 13 and 14, values presented graphically for each individual based on position at tables relative to infected source).
• The infection risk evaluation from our current CFD is only derived from the aerosol exposure index. To yield a more substantiated metric of infection risk, a relevant infection-dose model, currently not available for SARS-CoV-2, is needed.</td></tr>
</tbody>
</table>

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		widely reported by the media. To demonstrate direct linkage between the simulation results (under different ventilation and thermal settings) and reported infection patterns as well as the corresponding detailed physical mechanisms that lead to airborne disease transmission. We employed an advanced in-house large eddy simulation solver and other cutting-edge numerical methods to resolve complex indoor processes simultaneously, including turbulence, flow–aerosol interplay, thermal effect, and the filtration effect by air conditioners. Using the aerosol exposure index derived from the simulation, we are able to provide a spatial map of the airborne infection risk under different settings.		
SARS-CoV-2	Aganovic et al., 2022 (13) Norway	The article aimed to analyze the impact of Relative Humidity (RH) and increasing air exchange rates on the risk of infection of five indoor airborne respiratory viruses. **Methodology:** The methods involve modelling the impact of indoor RH and ventilation rates on infection risk. This is achieved by using equations that account for parameters such as	**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: The study compares three ventilation rates, 0.5 h−1, which is typical for residential environments in Nordic countries, 2 h−1, which can be considered typical for offices and schools with mechanical ventilation, and 6 h−1, which is recommended for patient rooms by ASHRAE	- RH range of 20–80% and air temperature of 20–25 °C. - The authors considered three ventilation rates, 0.5 h− 1, which is typical for residential environments in Nordic countries, 2 h− 1, which can be considered typical for offices and schools with mechanical ventilation, and 6 h− 1, which is recommended for patient rooms by ASHRAE Standard 170 for health care facilities. - The findings show that the impact of RH is higher when increasing the ventilation rate from 0.5 to 2 h−1 and slightly lower when ventilation is increased to 6 h−1. - Compared to increased RH at a constant ventilation rate, increasing the ventilation rate to 2.0 h−1 will decrease the infection risk for all viruses (relative decrease in infection risk is ≈ 38% to ≈ 50%) except for rhinovirus, where the effect is smaller (5.7% relative decrease).

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		molar mass, density, temperature, mass fraction, dissociation number, and osmotic coefficient. These parameters are used to calculate the droplet absorption rate and deposition in the respiratory system. Additionally, the methods explore how RH and ventilation rates affect the transmission of respiratory viruses in indoor setting .	Standard 170 for health care facilities. **Key outcomes:** Infection Risk	• Increasing ventilation from 0.5 to 2 h-1 with a constant relative humidity of 20% reduced the risk of SARS-CoV-2 infection between 40 and 50.5%. • Increasing the ventilation rate to 6 h^{-1} will dominate the reducing infection risk regardless of virus type, ranging from up to ≈ 70% relative decrease for adenovirus ≈ 75–78% for SARS-CoV-2, and up to ≈ 84% for Influenza.
			Environmental conditions to target for optimal ventilation	
			Intervention: The study compares low RH (37%) to high RH (83.5%) at a constant low ventilation rate (0.5 h^{-1} **Key outcomes:** Infection Risk	• RH range of 20–80% and air temperature of 20–25 °C. • The authors considered three ventilation rates, 0.5 h− 1, which is typical for residential environments in Nordic countries, 2 h− 1, which can be considered typical for offices and schools with mechanical ventilation39,40, and 6 h− 1, which is recommended for patient rooms by ASHRAE Standard 170 for health care facilities. • The findings show that the impact of RH is higher when increasing the ventilation rate from 0.5 to 2 h^{-1} and slightly lower when ventilation is increased to 6 h^{-1}. For SARS-CoV-2, increasing RH to 50% will generally increase the infection risk; however, this effect will strongly depend on the aerosol dry solution composition (amount of proteins vs. salts). At a higher salt to protein ratio (3.6:1), the impact of increased RH from ≈ 20 to ≈ 35% may increase the relative infection risk more than when RH is increased to 50%. For a lower salt to protein ratio (2.5:1), an increased RH to ≈ 50% will increase the infection risk. Generally, regardless of the dry solution composition, humidification will increase the infection risk via long-range airborne transmission of SARS-CoV-2. Compared to increased RH at a constant ventilation rate, increasing the ventilation rate to 2.0 h^{-1} will decrease the infection risk for all viruses (relative decrease in infection risk is ≈ 38% to ≈ 50%) except for rhinovirus, where the effect is smaller (5.7% relative decrease). • Increasing the ventilation rate to 6 h^{-1} will dominate the reducing infection risk regardless of virus type, ranging from up to ≈ 70% relative decrease for adenovirus ≈ 75–78% for SARS-CoV-2, and up to ≈ 84% for Influenza.
Influenza			**Numbers of air changes per hour (ACH) for optimal ventilation**	
			Intervention: The study compares three ventilation rates, 0.5 h−1, which is typical for residential environments in Nordic countries, 2 h−1, which can be considered typical for offices and schools with	• RH range of 20–80% and air temperature of 20–25 °C. • The authors considered three ventilation rates, 0.5 h− 1, which is typical for residential environments in Nordic countries, 2 h− 1, which can be considered typical for offices and schools with mechanical ventilation, and 6 h− 1, which is recommended for patient rooms by ASHRAE Standard 170 for health care facilities. • The findings show that the impact of RH is higher when increasing the ventilation rate from 0.5 to 2 h^{-1} and slightly lower when ventilation is increased to 6 h^{-1}.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
			mechanical ventilation, and 6 h−1, which is recommended for patient rooms by ASHRAE Standard 170 for health care facilities. **Key outcomes:** Infection Risk	Compared to increased RH at a constant ventilation rate, increasing the ventilation rate to 2.0 h^{-1} will decrease the infection risk for all viruses (relative decrease in infection risk is ≈ 38% to ≈ 50%) except for rhinovirus, where the effect is smaller (5.7% relative decrease). - Increasing ventilation from 0.5 to 2 h-1 with a constant relative humidity of 20% reduced the risk of influenza infection by 42.3%. - Increasing the ventilation rate to 6 h^{-1} will dominate the reducing infection risk regardless of virus type, ranging from up to ≈ 70% relative decrease for adenovirus ≈ 75–78% for SARS-CoV-2, and up to ≈ 84% for Influenza.
			Environmental conditions to target for optimal ventilation	
			Intervention: The study compares low RH (37%) to high RH (83.5%) at a constant low ventilation rate (0.5 h^{-1} **Key outcomes:** Infection Risk	- RH range of 20–80% and air temperature of 20–25 °C. - The authors considered three ventilation rates, 0.5 h− 1, which is typical for residential environments in Nordic countries, 2 h− 1, which can be considered typical for offices and schools with mechanical ventilation39,40, and 6 h− 1, which is recommended for patient rooms by ASHRAE Standard 170 for health care facilities. - The findings show that the impact of RH is higher when increasing the ventilation rate from 0.5 to 2 h^{-1} and slightly lower when ventilation is increased to 6 h^{-1}. For SARS-CoV-2, increasing RH to 50% will generally increase the infection risk; however, this effect will strongly depend on the aerosol dry solution composition (amount of proteins vs. salts). At a higher salt to protein ratio (3.6:1), the impact of increased RH from ≈ 20 to ≈ 35% may increase the relative infection risk more than when RH is increased to 50%. For a lower salt to protein ratio (2.5:1), an increased RH to ≈ 50% will increase the infection risk. Generally, regardless of the dry solution composition, humidification will increase the infection risk via long-range airborne transmission of SARS-CoV-2. - Compared to increased RH at a constant ventilation rate, increasing the ventilation rate to 2.0 h^{-1} will decrease the infection risk for all viruses (relative decrease in infection risk is ≈ 38% to ≈ 50%) except for rhinovirus, where the effect is smaller (5.7% relative decrease). - Increasing the ventilation rate to 6 h^{-1} will dominate the reducing infection risk regardless of virus type, ranging from up to ≈ 70% relative decrease for adenovirus ≈ 75–78% for SARS-CoV-2, and up to ≈ 84% for Influenza.
SARS-CoV-2	Stabile et al., 2021(50) Germany	The study focuses on assessing ventilation requirements in classrooms to reduce the airborne transmission of infectious diseases, particularly	**HVAC systems (e.g. displacement, mixing systems)**	
			Intervention: Manual Airing Procedures: Airing cycles, involving opening and	- The study indicates that manual airing procedures, although less efficient than mechanical ventilation systems, can still contribute to reducing the transmission potential of airborne infectious diseases in school classrooms. By adjusting window opening and closing periods based on real-time monitoring of indoor CO2

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr>
<td rowspan="3"></td>
<td rowspan="3"></td>
<td rowspan="3">during pandemics like COVID-19. It compares mechanically ventilated and naturally ventilated classrooms, proposing feedback control strategies based on CO_2 monitoring.

Methodology: The study presents a methodology for managing air quality in classrooms to minimize the spread of airborne diseases. It calculates the Air Exchange Rate (AER) based on predefined scenarios, including different activities and durations. For mechanically ventilated classrooms, a control unit evaluates and sets the required AER. For naturally ventilated classrooms, manual airing cycles are suggested to increase the AER, with a feedback control strategy based on exhaled CO_2 monitoring. The methodology utilizes virus mass balance equations to assess the required ventilation and introduces a combined approach integrating mechanical ventilation systems and manual airing procedures. The study provides insights into optimizing indoor air quality and reducing disease transmission potential. AERNV and AERMA are the air exchange rates with window close (natural ventilation, NV) and window</td>
<td>closing windows, are adjusted based on real-time monitoring of indoor CO_2 concentration to achieve a $R_{event} < 1$

Interventions for Mechanically Ventilated Classrooms: Implementation of required constant AERs for different scenarios to maintain $R_{event} < 1$. The scenarios include a teacher speaking loudly for 60 minutes (T-60-LS) and a student attending lessons for 300 minutes, breathing orally (S-0%-S), among others.
Comparator: against standard or lower AERs not designed to specifically maintain $R_{event} < 1$.

Key outcomes: Event reproduction number (R_{event}): the expected number of new infections arising from a single infectious individual at a specific event. Acceptable Revent < 1</td>
<td>concentration, manual airing can achieve a Revent < 1 under certain conditions. However, the effectiveness of manual airing is heavily dependent on factors such as the duration and frequency of airing cycles, as well as the variability of air exchange rates (AERNV and AERMA).
• The implementation of mechanical ventilation systems, particularly with a constant air volume flow, is shown to effectively reduce the transmission potential of airborne infectious diseases in school classrooms.
• The study demonstrates that maintaining a high and AER through mechanical ventilation can rapidly decrease quanta concentration, individual risk of infection, and indoor CO2 levels.

<table>
<tr><th colspan="3">Required constant AER (h− 1) to maintain a Revent < 1 for all the scenarios investigated for SARS-CoV-2 for mechanically ventilated classrooms.</th></tr>
<tr><th colspan="2">Scenarios</th><th>AER (h^{-1})</th></tr>
<tr><td>Base scenarios</td><td>T-60-LS</td><td>9.5</td></tr>
<tr><td></td><td>S-0%-S</td><td>0.8</td></tr>
<tr><td>Student's speaking effect</td><td>S-10%-S</td><td>1.5</td></tr>
<tr><td></td><td>S-20%-S</td><td>2.1</td></tr>
<tr><td></td><td>S-30%-S</td><td>2.8</td></tr>
<tr><td></td><td>S-40%-S</td><td>3.5</td></tr>
<tr><td>Class duration effect</td><td>T-55-LS</td><td>8.6</td></tr>
<tr><td></td><td>T-50-LS</td><td>7.8</td></tr>
<tr><td></td><td>T-45-LS</td><td>6.9</td></tr>
<tr><td></td><td>T-40-LS</td><td>6.1</td></tr>
<tr><td>Voice modulation effect</td><td>T-60-S</td><td>0.8</td></tr>
<tr><td>Mask effect</td><td>T-60-LS-M</td><td>5.8</td></tr>
<tr><td>Voice modulation & mask effect</td><td>T-60-S-M</td><td>0.2</td></tr>
</table>
</td>
</tr>
<tr><th colspan="2">Combinations of ventilation and filtration strategies</th></tr>
<tr>
<td>Intervention:
Interventions for Mechanically Ventilated</td>
<td>• The study suggests that a combined approach of utilizing both mechanical ventilation systems and manual airing procedures may be particularly beneficial in</td>
</tr>
</table>

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		open (manual airing, MA), respectively.	Classrooms: Implementation of required constant AERs for different scenarios to maintain $R_{event} < 1$. The scenarios include a teacher speaking loudly for 60 minutes (T-60-LS) and a student attending lessons for 300 minutes, breathing orally (S-0%-S), among others. Comparator: against standard or lower AERs not designed to specifically maintain $R_{event} < 1$. Interventions for Naturally Ventilated Classrooms: Adoption of manual airing procedures based on airing cycles (periods with windows alternately opened and closed) determined to maintain $R_{event} < 1$. This approach is supported by a feedback control strategy using CO_2 monitoring to adjust airing in real-time. Comparator: ad-hoc ventilation practices not optimized to maintain $R_{event} < 1$. **Key outcomes:** Event reproduction number (R_{event}): the expected number of new infections	classrooms where mechanical ventilation systems alone may not be feasible or sufficient. • By integrating the strengths of mechanical ventilation systems (consistent high AER) and manual airing (real-time adjustments based on CO_2 monitoring), this approach can provide effective ventilation even in challenging environments.

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td rowspan="3"></td><td rowspan="3"></td><td>arising from a single infectious individual at a specific event.
Acceptable $R_{event} < 1$</td><td></td></tr>
<tr><td rowspan="2">Influenza</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>Intervention: Manual Airing Procedures: Airing cycles, involving opening and closing windows, are adjusted based on real-time monitoring of indoor CO_2 concentration to achieve a $R_{event} < 1$.

Key outcomes: Event reproduction number (R_{event}): the expected number of new infections arising from a single infectious individual at a specific event.
Acceptable $R_{event} < 1$</td><td>- The required AER for seasonal influenza infected subjects is not reported since it is < 0.1 h^{-1} for all the scenarios under investigation. Thus, all the ventilation techniques are able to protect against the spreading of the seasonal influenza virus in classroom through airborne transmission.
Author concluded that seasonal influenza presents a negligible transmission potential via airborne route in classroom, even when low ventilation is provided; this is due to the low emission rates typical of such virus, indeed the median value resulted more than 10-fold lower than the SARS-CoV-2 one.</td></tr>
<tr><td rowspan="2">Measles</td><td rowspan="2">Azimi et al., 2020(11)

United States</td><td rowspan="2">The paper focuses on estimating the transmission risk of measles in U.S. schools by developing risk models that consider factors like vaccination coverage, air filtration, ventilation rates, and infection control strategies.
Methodology: The core of the methodology involved the development of risk models that incorporate a range of parameters, including air circulation, vaccination coverage, age of individuals, school setups (e.g., different school settings and HVAC systems), and</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>Intervention
Regular Scenario: Enhancing ventilation to levels that are higher than the minimum requirements but still within a cost-effective range for schools.
Advanced Scenario: Significantly increasing the ventilation rate to levels that are less common and more costly but feasible for reducing airborne pathogen risk.</td><td>Increased Ventilation Rate:
The authors assumed double of the required ventilation rates in classrooms (i.e., 13.4 L/s-person) and cafeteria (i.e., 9.4 L/s-person) as the regular ventilation-related control scenario in the modeled schools. For the advanced ventilation-related control scenario, they assumed double of maximum required ventilation rate in educational facilities for the infector's classroom and recirculation space (i.e., 19.0 L/s-person), and increased the common space ventilation rates to the double of the required ventilation rates for dining rooms (i.e., 10.2 L/s-person).

Regular and advanced ventilation-related control strategies had average effectiveness of 18% and 28%, respectively.

<table><tr><th>Strategy</th><th>Measles Transmission Risk Reduction (%)</th></tr></table></td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3">infection control strategies. The Wells-Riley model is adapted for multi-zone school environments and Monte-Carlo simulations are used to handle parameter variability and uncertainty. A nationally representative archetypal school building model is created to estimate measles risk in various US schools. The Quanta Generation Rate is calculated from actual outbreaks in schools to refine model parameters. Sensitivity analyzes are performed to identify factors that impact the risk of transmission.</td><td>Comparators: For each intervention, the comparator was the basic infection-control scenario of the School Building Arch: ventilation rate of 6.7 L/s-person for infector’s classroom and the recirculation space, and 4.7 L/s-person in common spaces.

Key outcomes:
Reduction in Measles Transmission Risk</td><td><table>
<tr><td rowspan="2">Increased Ventilation Rate</td><td>Regular Ventilation Enhancement</td><td>From 46% to 38% among unvaccinated students</td></tr>
<tr><td>Advanced Ventilation Enhancement</td><td>From 46% to 33% among unvaccinated students</td></tr>
</table></td></tr>
<tr><td colspan="2">Filters and filter ratings to use in a mechanical ventilation system</td></tr>
<tr><td>Intervention:
Regular Scenario: Upgrading air filters to a higher efficiency level within cost-effective and commonly adopted standards for schools.
Advanced Scenario: Implementing High-Efficiency Particulate Air (HEPA) filters, representing a more extreme risk-reduction approach.
Comparators: For each intervention, the comparator was the basic infection-control scenario of the School Building Arch: MERV-8</td><td>Air Filtration Improvement:
• Upgrading to MERV-13 filters (regular scenario) and HEPA filters (advanced scenario) reduced the average number of infected students by approximately 28% and 33%, respectively.
<table>
<tr><th colspan="2">Strategy</th><th>Measles Transmission Risk Reduction (%)</th></tr>
<tr><td rowspan="2">Air Filtration Improvement</td><td>Air Filtration (MERV-8 to MERV-13)</td><td>From 45% to 32% among unvaccinated students</td></tr>
<tr><td>Air Filtration (MERV-8 to HEPA)</td><td>From 45% to 29% among unvaccinated students</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td></td><td>Key outcomes:
Reduction in Measles Transmission Risk</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Portable air cleaners</td></tr>
<tr><td></td><td></td><td></td><td>Intervention:
Regular Scenario: Placing air purifiers with a Clean Air Delivery Rate (CADR) of 400 CFM in classrooms.
Advanced Scenario: Doubling the CADR to 800 CFM for air purifiers in classrooms.
Comparators: For each intervention, the comparator was the basic infection-control scenario of the School Building Arch.: No air purifiers

Key outcomes:
Reduction in Measles Transmission Risk</td><td>Use of Air Purifiers:
Regular CADR of 400 CFM decreased the number of infected cases by 18%, while the advanced scenario of 800 CFM increased the effectiveness to 31%.
<table>
<tr><th colspan="2">Strategy</th><th>Measles Transmission Risk Reduction (%)</th></tr>
<tr><td>Use of Air Purifiers</td><td>Air Purification (CADR 400 CFM)</td><td>From 45% to 37% among unvaccinated students</td></tr>
<tr><td></td><td>Air Purification (CADR 800 CFM)</td><td>From 45% to 31% among unvaccinated students</td></tr>
</table></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Combinations of ventilation and filtration strategies</td></tr>
<tr><td></td><td></td><td></td><td>Intervention:
Regular Combination Scenarios: Combining two regular control approaches (filtration-ventilation and ventilation-purification) reduced the median infection risk among susceptible students to 28% and 31%, respectively.
Advanced Combination Scenario: Applying all</td><td>Combination of Interventions:
Combining all regular and advanced control scenarios reduced the average number of infected cases up to 45% and 56%, respectively, demonstrating the high impact of integrated building designs on reducing airborne disease transmission in schools.
<table>
<tr><th colspan="2">Strategy</th><th>Measles Transmission Risk Reduction (%)</th></tr>
<tr><td>Air Filtration Improvement</td><td>Air Filtration (MERV-8 to MERV-13)</td><td>From 45% to 32% among unvaccinated students</td></tr>
<tr><td></td><td>Air Filtration (MERV-8 to HEPA)</td><td>From 45% to 29% among unvaccinated students</td></tr>
<tr><td>Increased Ventilation Rate</td><td>Regular Ventilation Enhancement</td><td>From 46% to 38% among unvaccinated students</td></tr>
<tr><td></td><td>Advanced Ventilation Enhancement</td><td>From 46% to 33% among unvaccinated students</td></tr>
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</table>

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<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td></td><td>three techniques (filtration, ventilation, and purification) together lowered the median infection risk to 19% for advanced infection control strategies. Comparators: For each intervention, the comparator was the basic infection-control scenario of the School Building Arch.

Key outcomes:
Reduction in Measles Transmission Risk</td><td><table>
<tr><td rowspan="2">Use of Air Purifiers</td><td>Air Purification (CADR 400 CFM)</td><td>Reduction to 37% among unvaccinated students</td></tr>
<tr><td>Air Purification (CADR 800 CFM)</td><td>Reduction to 31% among unvaccinated students</td></tr>
<tr><td rowspan="4">Combination scenarios</td><td>Regular filtration + ventilation</td><td>Reduction to 28% among unvaccinated students</td></tr>
<tr><td>Regular purification + ventilation</td><td>Reduction to 31% among unvaccinated students</td></tr>
<tr><td>Regular Filtration + Ventilation + Purification</td><td>Reduction to 24% among unvaccinated students</td></tr>
<tr><td>Advanced filtration + Ventilation + purification</td><td>Reduction to 19% among unvaccinated students</td></tr>
</table></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Liu et al., 2023 (56)</td><td rowspan="2">The aim of the study was to evaluate the decontamination performance of two cabin ventilation systems, the DV system and the MV(MV) system, in preventing contamination by virus (COVID-19)-laden droplets. The influence of the ventilation system and wind velocity on infection probability was also studied.

Methodology: the authors used a 3D Computational Fluid Dynamics (CFD) modelling to simulate the cabin segment of an aircraft, focusing on the dispersion and behavior of virus-laden droplets under two different ventilation systems: DV and MV(MV) systems. The cabin model is simplified to include</td><td colspan="2">**HVAC systems (e.g. displacement, mixing systems)**</td></tr>
<tr><td>**Intervention:**
displacement ventilation and mixing ventilation. Variation in Inlet Velocity (1 m/s and 1.5 m/s) were compared within the context of the DV system.

Key outcomes: Infection Risk</td><td>**DV System vs MV System:**
• The DV system was found to concentrate droplets more on the side near the window compared to the MV system. However, the infection probability for passengers in the DV system was higher than in the MV system in some positions, particularly for passengers seated near the window.
• Conversely, for passengers seated near the aisle, the infection probability was significantly higher in the MV system than in the DV system. Overall, while the DV system could remove pollutants more effectively than the MV system, it was not superior to the MV system locally in terms of reducing the risk of contamination in the passenger inhalable area.

Variation in Inlet Velocity:
• The number of suspended droplets was greatest when ventilation was not used.
• At an inlet velocity of 1 m/s, the number of droplets escaping from the outlet was the largest, while the proportion of droplets suspended in the air was the lowest at the same time point when the inlet velocity was increased to 1.5 m/s.
• This suggests that a higher inlet velocity might contribute to a decreased infection probability by facilitating a higher rate of gas displacement in the aircraft cabin.</td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td>only three rows of seats, each equipped with a manikin to represent passengers. The manikins have mouth openings to simulate the release of droplets, and the study considers the impact of different droplet sizes and environmental conditions on droplet dispersion and evaporation. The Euler-Lagrange approach is used for modelling droplet dispersion, and the Wells-Riley model is employed to assess the risk of respiratory disease transmission.</td><td></td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">O' Donovan et al., 2023 (77)

Ireland</td><td rowspan="2">The study aims to develop a method for assessing and reducing infectious disease risk in teaching spaces, considering ventilation systems and seasonal changes. It also presents a three-stage risk assessment model for design stages.

Methodology: The study employed a comprehensive methodology to assess the risk of airborne infection in lecture room environments, particularly focusing on the design stage of retrofitting ventilation systems. The methodology involved evaluating various retrofit scenarios that combined different ventilation strategies, including natural and mechanical ventilation, infiltration rates, and the use of air cleaners. Additionally, the study</td><td colspan="2">Building/room designs and ventilation types in building designs</td></tr>
<tr><td>Intervention:
1) the existing case study building scenario; using top hung outward opening windows with single-sided NV only (i.e. the original 1974 building/envelope design)
2) upgrades to the ventilation openings (i.e. with an airflow guiding louvre or different NV components)
3) upgrades to building air-tightness levels
4) the use of an MV system.

Key outcomes:
Infectious Risk</td><td>• While natural ventilation can suppress viral growth under certain conditions, it cannot provide consistent protection against airborne transmission of respiratory viruses such as SARS-CoV-2. A poorly performing NV systems could lead to higher infectious risk (32%–76% of daily RI numbers greater than 1), however, when designed correctly, this underperformance can be limited (0%–11% of daily RI numbers greater than 1, depending on the location and system)
• Despite all NV scenarios exhibiting the same worst case maximum RI (RI = 8.6) (which indicates a scenario when no wind or buoyancy driven flows are possible), when any ventilation system is employed, this results in a substantial decrease in the average RI number, where all retrofit scenarios with ventilation systems are likely to lead to average RI numbers under 0.5, which should suppress the growth of the virus.</td></tr>
</table>

<table>
<thead>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
</thead>
<tbody>
<tr><td></td><td></td><td>considered the efficiency of masks worn by occupants, class sizes, and the impact of seasonality in different climates on airborne infection risk. The Wells-Riley model was utilized to calculate the probability of infection, considering several parameters such as airflow rates, quanta emission rates, and indoor temperatures. Seven specific ventilation retrofit scenarios were assessed, incorporating natural ventilation, mechanical ventilation, and architectural louvres.</td><td></td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Ghoroghi et al, 2022 (59)

United Kingdom</td><td rowspan="2">The objective of this study was to model and analyze the quality of the indoor environment, the related safety measures and their effectiveness in preventing the spread of the SARS-CoV-2 virus.

Methodology: The study utilizes simulation models to assess the impact of preventative measures on the safety of individuals in various indoor settings. Three types of ventilation scenarios are analyzed using a Discrete Event Simulation (DES) model. The simulation model evaluates possible responses to infection in public indoor environments, considering the efficacy of different rates of wearing surgical face masks, vaccination coverage, and performing hand hygiene.</td><td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td></tr>
<tr><td>Intervention: Mechanical ventilation with no optimization, Mixed ventilation with no optimization, and Mixed ventilation with optimization

Key Outcomes: risk transmission (% area of risk), probability of secondary infection.</td><td>- Mechanical ventilation alone is not entirely effective in eliminating stagnant air zones where the risk of disease transmission is higher. This is because mechanical systems, depending on their design and operation, may not achieve the high air change rates required to minimize the risk of aerosol infections. The presence of more stagnant areas—where air velocity is less than 0.1 m/s—suggests that mechanical ventilation is less effective at removing air, potentially allowing for the accumulation of infectious particles.
- Natural ventilation, on the other hand, can significantly improve air circulation, achieving higher air change rates compared to mechanical ventilation alone. This is particularly true when weather conditions are favorable, allowing for the full opening of windows to enhance air exchange. However, natural ventilation also has its limitations, such as the potential for CO_2 accumulation at lower levels near windows, indicating that while air movement is increased, it may not be optimally distributed throughout space.

<table>
<tr><th colspan="4">The mean probability of secondary infected individuals for the base case (without another preventive strategy)</th></tr>
<tr><th>Type of Ventilation</th><th>Primary Infected 1.3 %</th><th>Primary Infected 0.4 %</th><th>Primary Infected 1.7 %</th></tr>
<tr><td>Mechanical Ven No Optimisation</td><td>5.06×10^{-5}</td><td>2.55×10^{-5}</td><td>7.78×10^{-5}</td></tr>
</table></td></tr>
</tbody>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year/ Country</th><th>Objective / Methods</th><th>Interventions /Outcomes /Scenarios</th><th>Summary of Findings</th></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3">The study's setting is the Forum within the Queen's Buildings at Cardiff University, an informal space with mixed ventilation strategies and specific hygiene measures in place due to the COVID-19 pandemic.</td><td></td><td>
<table>
<tr><td>Mixed Ven No Optimisation</td><td>5.21×10^{-5}</td><td>2.60×10^{-5}</td><td>7.97×10^{-5}</td></tr>
<tr><td>Mixed Ven with Optimisation</td><td>3.90×10^{-5}</td><td>1.89×10^{-5}</td><td>6.00×10^{-5}</td></tr>
</table>

Authors concluded that while natural and mixed ventilation methods show a higher potential in reducing transmission risk compared to mechanical ventilation alone, none of these strategies can fully mitigate the risk of aerosol infections on their own.</td></tr>
<tr><td colspan="2">Combinations of ventilation and filtration strategies</td></tr>
<tr><td>Intervention: Mechanical ventilation with no optimization, Mixed ventilation with no optimization, and Mixed ventilation with optimization

Key Outcomes: risk transmission (% area of risk), probability of secondary infection.</td><td>

Mixed ventilation strategies, combining both mechanical and natural ventilation, aim to optimize air exchange and minimize stagnant zones within indoor spaces. This approach can achieve higher air change rates, potentially up to 23.8 ACH, compared to mechanical ventilation alone. Despite this improvement, some stagnant areas may remain, indicating that even mixed ventilation cannot completely eliminate the risk of aerosol transmission.
The type of ventilation played a significant role, with Ventilation type III (Mixed ventilation with optimization) showing the lowest risk of transmission compared to the other ventilation types.

<table>
<tr><th colspan="4">The mean probability of secondary infected individuals for the base case (without another preventive strategy)</th></tr>
<tr><th>Type of Ventilation</th><th>Primary Infected 1.3 %</th><th>Primary Infected 0.4 %</th><th>Primary Infected 1.7 %</th></tr>
<tr><td>Mechanical Ven No Optimisation</td><td>5.06×10^{-5}</td><td>2.55×10^{-5}</td><td>7.78×10^{-5}</td></tr>
<tr><td>Mixed Ven No Optimisation</td><td>5.21×10^{-5}</td><td>2.60×10^{-5}</td><td>7.97×10^{-5}</td></tr>
<tr><td>Mixed Ven with Optimisation</td><td>3.90×10^{-5}</td><td>1.89×10^{-5}</td><td>6.00×10^{-5}</td></tr>
</table>

Authors concluded that while natural and mixed ventilation methods show a higher potential in reducing transmission risk compared to mechanical ventilation alone, none of these strategies can fully mitigate the risk of aerosol infections on their own. The effectiveness of any ventilation intervention is contingent upon the specific configuration of the indoor space, including the size, number, and arrangement of openings, as well as the operational strategy of the ventilation system. Therefore, a comprehensive approach, including proper hygiene practices and possibly other preventive measures, is essential for significantly reducing the risk of airborne disease transmission.</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td></tr>
</table>

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
SARS-CoV-2	Niu et al., 2022 (47) China	The paper discusses the analysis of indoor environmental parameters in office buildings, focusing on factors like air temperature, humidity, PM 2.5 concentration, and fresh air systems. **Methodology:** The study used a mixed methods approach to assess the indoor environment of an office building, combining objective physical measurements (like air temperature, Relative Humidity (RH), PM 2.5 concentration, air velocity, and fresh air volume) and subjective surveys from occupants about their satisfaction with the indoor air quality, temperature, and overall environmental quality. The data from these measurements and surveys were analyzed using statistical tools such as Spearman correlation statistics and Gray relational analysis. The study also evaluated the impact of fresh air systems on the indoor environment, especially in terms of air quality and temperature, and assessed their effectiveness in regular epidemic prevention and control, with a particular focus on the COVID-19 pandemic.	**Intervention:** The average daily fresh air volume is 33.5 m3/h per capita for full-time operation and 31.8 m3/h per capita for part-time operation **Key outcomes:** Infection probability	• The calculation shows that the probability of infection for indoor personnel in this office building is 2.8% and 4.9% for the full-time and part-time modes of operation, respectively. • The probability of infection of indoor personnel with the virus causing COVID-19 under the two existing fresh air system operation modes was calculated and found to be less than 5%. This suggests that both operation modes are relatively effective in minimizing the risk of COVID-19 infection among indoor personnel.
SARS-CoV-2	Ren et al., 2022 (52) China	Different ventilation modes and supply air parameters were studied to determine their impact on environmental quality and	**HVAC systems (e.g. displacement, mixing systems)**	
			Intervention: Mechanical Ventilation (MV), Supply Fan Rotary Controller-1	• The infection risk for the MV system was all greater than 3%, which increased with the decrease of the supply air velocity.

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		passenger satisfaction in subway stations and carriages. **Methodology:** CFD simulations were used to analyze the effects of different ventilation modes, specifically mechanical ventilation (MV) and SFRC, on airflow velocity, temperature distribution, and air concentration. CO_2. The simulations solved the Reynolds-averaged Navier-Stokes equations using the RNG k-ε model, ensuring detailed analysis of ventilation performance. To ensure the accuracy of the CFD results, a network independence analysis was performed. Various evaluation models were used, including air diffusion performance index (ADPI), predicted mean vote (PMV), contaminant removal efficiency (PRE), infection probability, and cooling load. The Analytical Hierarchy Process (AHP) method was used for an evaluation of benefits.	(SFRC-1), and Supply Fan Rotary Controller-2 (SFRC-2). **Key outcomes:** Infection probability	- The SFRC-1 could reduce the infection probability by at least 2%. The SFRC-2 system showed favorable behavior in the mitigation of airborne transmission, attaining an infection risk below 0.4%. Authors concluded that the SFRC-2 system is recommended for improving the air quality in the occupied area of the carriage and reducing the infection probability of passengers when combined with optimized supply air parameters.
			HVAC systems (e.g. displacement, mixing systems)	
SARS-CoV-2	Aganovic et al., 2022 (64) Norway	The study aims to extend the Wells-Riley model to provide more accurate infection risk calculations in spaces with non-uniform air distribution. The study introduces a zonal modelling approach that divides enclosed spaces into multiple zones, considering different airflow distribution methods	**Intervention:** Incomplete Mixing Ventilation (MV) (where air is not uniformly mixed, and temperature differences exist between supply and exhaust air). Complete MV scenarios (where air and temperature are	**Incomplete Mixing Ventilation vs. Complete Mixing Ventilation**: - The temperature difference has a notable impact on infection risk when the air is heated compared to the isothermal air supply. - Increasing the supply temperature to ΔT = 10 K higher than exhaust air relatively increases infection risk up to more than 15% for low ventilation rates (0.5 ACH) and up to 10% for higher ventilation rates (6 ACH) after 90 minutes compared to complete mixing (ΔT = 10 K).

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<td>such as mixing ventilation, DV, and protected zone ventilation.

Methodology: The article discusses the extension of the Wells-Riley model to consider the spatial distribution of infection risk. It introduces a zonal modelling approach that divides spaces into multiple zones with different airflow distributions and uses transient state calculations of quanta concentration and ventilation efficiency values. The impact of various ventilation methods on the risk of infection is evaluated using a modified Wells-Riley equation. The study incorporates first-order differential equations to describe the balance of flow and quanta concentrations and uses experimental studies to develop a three-zone theoretical ventilation model. This model includes equations for quanta flow equilibrium and considers the virus emission rate. Finally, the text provides a theoretical framework to evaluate the effectiveness of different ventilation systems to reduce the risk of SARS-CoV-2 transmission.</td>
<td>uniformly mixed). Displacement ventilation (DV).

Key outcomes: Infection risk</td>
<td>Displacement Ventilation:
The study also evaluates the effectiveness of DV by transforming the simplified two-zone model concept of contaminant distribution for DV to a two-zone exposure model for assessing the long-range airborne transmission risks in indoor environments.
• The relative difference to complete mixing conditions is mostly caused by the position of the neutral plane that depends on the heat load, amount of supplied air, and temperature difference between supply and exhaust air.

Protected Zone Ventilation:
This intervention involves separating an indoor space into two well-mixed subzones of equal volume by using a downward plane jet.
• Protective zone ventilation decreases the infection risk in the protected zone with the susceptible person while it increases the infection risk in the polluted zone compared to completely mixing conditions.

Relative comparison of the infection risk overestimation (+)/underestimation (-) of a single-zone air-two-zone airflow distribution method compared to completely flow distribution
<table>
<tr><th>Strategy</th><th>ACH</th><th>DT = 2K</th><th>DT = 5K</th><th>DT = 10K</th></tr>
<tr><td>Incomplete mixing ventilation</td><td>0.5</td><td>38.4%+</td><td>56.3 %+</td><td>77.5 %+</td></tr>
<tr><td></td><td>2.0</td><td>36.2 %+</td><td>56.0 %+</td><td>82.8 %+</td></tr>
<tr><td></td><td>6.0</td><td>34.1 %+</td><td>52.9 %+</td><td>78.7 %+</td></tr>
<tr><td>DV (infected person standing/susceptible person standing</td><td>0.5</td><td>13.8 %+</td><td>18.0 %+</td><td>21.5 %+</td></tr>
<tr><td></td><td>2.0</td><td>3.5 %+</td><td>4.8 %</td><td>5.9 %</td></tr>
<tr><td></td><td>6.0</td><td>+ <0.1 %</td><td>+ <0.1 %</td><td>+< 0.1 %</td></tr>
<tr><td>DV (infected person standing/susceptible person sitting)</td><td>0.5</td><td>37.7 %-</td><td>49.0 %</td><td>59.7 %-</td></tr>
<tr><td></td><td>2.0</td><td>3.5 %+</td><td>4.7+</td><td>5.9 %+</td></tr>
<tr><td></td><td>6.0</td><td>+ <O. 1 %</td><td>+ < 0.1 %</td><td>+ < 0.1 %</td></tr>
<tr><td>Protected zone ventilation</td><td>0.5</td><td>-10.4 %</td><td></td><td></td></tr>
<tr><td></td><td>2.0</td><td>-10.5 %</td><td></td><td></td></tr>
<tr><td></td><td>6.0</td><td>30.9 %-</td><td></td><td></td></tr>
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<tr>
<td rowspan="2">SARS-CoV-2</td>
<td rowspan="2">Osterman et al., 2022 (53)

Slovenia</td>
<td rowspan="2">The aim of the study is to examine the efficiency of ventilation systems, calculate the probability of infection due to the spread of coronavirus</td>
<td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td>
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<tr>
<td>Intervention:
Increasing ventilation capacity from 50% to 80%.</td>
<td>• Increased Ventilation Capacity: The probability of infection after 12 hours was significantly higher in scenarios with 50% ventilation capacity compared to those with 80% capacity. For instance, in large classrooms (LCR 2_G), the probability of infection reached 0.4% with 50% ventilation capacity. Increasing the *f* ventilation</td>
</tr>
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RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		through aerosol particles, verify the ventilation efficiency, and analyze the AC system to define occupancy in individual classrooms. **Methodology:** a comprehensive assessment of the ventilation efficiency in a selected educational building in Slovenia to calculate the transmission risks for COVID-19. This assessment includes an inspection of the building's ventilation systems, a review of mechanical installations, and measurements of various parameters such as the type of recuperation, surface area, height and volume of classrooms, air flow rate of the air-conditioning unit, and the type of air inlet. The study also utilizes the REHVA COVID-19 ventilation calculator, which is based on the Wells-Riley model, to determine the probability of infection for the selected space and human activity.	Classrooms without window opening vs. classrooms where windows were opened after each lecture and when CO_2 levels exceeded 1000 ppm. Increased Ventilation Capacity Use of CO_2 Sensors for Ventilation Control Natural Ventilation through Window Opening Equal Air Distribution in Small Classrooms **Key Outcomes**: Probability of infection Event reproduction number	capacity to 80% reduced the probability of infection, demonstrating the effectiveness of higher ventilation rates in reducing transmission risk. - Natural Ventilation through Window Opening: The practice of opening windows after each lecture and in response to elevated CO2 levels contributed to improved ventilation. Although specific quantitative results regarding the reduction in transmission risk were not provided, this intervention is implied to enhance air exchange and reduce potential airborne transmission risk in the studied educational setting. Authors concluded that the results underscore the effectiveness of increased mechanical ventilation capacity, the use of CO_2 sensors for ventilation control, and the incorporation of natural ventilation practices through window opening in mitigating transmission risk.
SARS-CoV-2	Sarhan et al., 2022 (51)	The aim of the study is to accurately predict the time it takes to become infected by sharing a passenger car with a patient of COVID-19 or similar viruses, and to evaluate the transmission of respiratory diseases in passenger cars. The study also aims to verify whether improving the tourism	**HVAC systems (e.g. displacement, mixing systems)**	
			Intervention: Different levels of air speeds were used: $v1 = 1.38$, $v2 = 2.6$, $v3 = 4.0$ and $v4 = 5.88$ m s^{-1}. **Key Outcomes:** exposure to airborne	The results are shown graphically, but the authors conclude that: - The concentration of contaminated droplets decreases with increasing air velocity of the HVAC system. - The observed decrease in the concentration of contaminated droplets could be attributed to the increase in the amount of fresh air exhausted through the HVAC unit from outside the car cabin. This fresh air will partially replace the contaminated air by pushing it out of the car through the ventilation system.

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		ventilation system would reduce the risk of contracting the coronavirus. **Methodology:** The methodology employed in the study involved a 3D computational fluid dynamics (CFD)-based investigation to simulate the airflow and aerosol transport within a passenger car. The Eulerian-Eulerian flow model, coupled with the k-ε turbulence approach, was used to track respiratory contaminants with a diameter ≥ 1 μm released by passengers. The airflow field in the computational domain (i.e., passenger car) was simulated using commercial CFD software AVL FIRE 2021, employing the Eulerian method coupled with the k-ε model. It was assumed that aerosol transport is a 2-phase flow where gas is the continuous phase, and the droplets/particles are a dispersed phase.	contagion studied through the number of contaminated particles inhaled by healthy subjects.	• The amount of fresh air will increase with increasing air velocity from the HVAC unit, thus causing a further reduction in the concentration of contaminated droplets inside the car cabin. This effect explains the reduction in the number of droplets inhaled by healthy passengers with the increase in air velocity of the HVAC unit. • Improving the ventilation system of tourism will reduce the risk of contracting coronavirus.
SARS-CoV-2	Guyot et al., 2022 (58) France	**Aim**: To assess the impact of ventilation strategies in buildings during a virus pandemic, particularly focusing on preventing the transmission of the virus in aerosolized form, such as SARS-CoV-2. **Methodology:** Multizone models are used to simulate the distribution of air flow within the	**HVAC systems (e.g. displacement, mixing systems)** **Interventions:** • A balanced constant airflow ventilation system (BV) • An exhaust-only constant airflow ventilation system (extracted airflows are the same for 1 and 2) (EV)	**Exhaust-only ventilation** (EV): Opening the quarantine room window always results in increased exposure of at least one other occupant, even in neighbors' homes. Some scenarios even cause extremely high relative increases. In fact, the scenarios can be separated into two groups: scenarios where the quarantine room door is sealed and scenarios with dilution strategies where this door is open. • The first group shows extreme increases in relative exposures compared to the reference case, while the second group shows moderate increases.

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		building. This involves dividing the building into zones and analyzing airflow patterns. The CONTAM software is used, considering the well-mixed air in each area of the apartment, to analyze the concentration of particles and the air flow. Additionally, numerical models are combined with real-world case study analyzes to investigate air flows, particle concentrations, and infection risk in multifamily buildings. The study focuses on a "reference apartment" within a real multifamily building, with the objective of analyzing the impact of various ventilation systems and door and window opening strategies on the movement of virus particles and the exposure of the occupants	• A humidity-based demand-controlled ventilation system (RH-DCV) This study considers a situation in which different windows are opened for 15 minutes, three times a day. In the reference case, all internal doors and all windows in the house are closed. **Key outcomes:** Infection risk, relative exposure.	• In the reference scenario, all occupants have less than a 1.6% probability of being infected by the virus. However, despite a 65% increase in exposure the risk remains very low. • Dilution strategies are much more effective since they allow almost all inhabitants to see their risk of infection decrease. **Sensitivity of the results to the other two ventilation systems:** There are only some differences with the EV system in the following points: • For the BV and RH-EV systems, all scenarios are beneficial for the quarantined occupant, with exposure decreases between -3 and -42%. • In the reference cases, the probability of infection is lower with BV (max. 1.15%) and higher with RH-DCV (max. 2.04%), compared to 1.65% max. with the VE. The authors conclude that when the quarantine room door is sealed, we observe that opening the quarantine room window always results in increased exposure and probability of infection for at least one other occupant, even in neighbors' apartments. When all internal doors are opened, we observe moderate impacts, with an increase in the exposure of occupants of the same apartments and their probability of infection, and a decrease for occupants located in other apartments. Based on the analysis of the distribution of air flows in this case study, we conclude that sealing the internal door has more influence than opening the window of the quarantine room, regardless of the ventilation system.
SARS-CoV-2	Das & Ramachandran, 2021(61) India	The study primarily investigates the risk of SARS-CoV-2 infection across various commute microenvironments, comparing the effectiveness of interventions like air conditioning (AC), vehicle speed, and window openings in reducing infection risk. **Methodology:** The use of a flexible Bayesian hierarchical model for estimating inhalation exposures. Additionally, the study utilized an equation developed by Fann et al. (2012)	**HVAC systems (e.g. displacement, mixing systems)** **Intervention:** various commuter micro-environments: air conditioned (AC) taxi, non-AC taxi, bus and autorickshaw. **Key outcomes:** Probability or risk of transmission or infection	• AC taxis showed a significantly higher probability of infection by SARS-CoV-2 compared to non-AC taxis. • Buses exhibited a lower probability of infection by SARS-CoV-2 compared to both AC and non-AC taxis. • Autorickshaws showed the lowest probability of infection by SARS-CoV-2 among all transportation modes studied. • The probability of infection due to SARS-CoV-2 was estimated to be 6.10×10^{-2} in AC-taxis, 1.71×10^{-2} in non-AC taxis, 1.43×10^{-2} in buses, and 1.99×10^{-4} in autorickshaws.

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		to estimate the annual number of adverse health outcomes in various scenarios, which considers the baseline incidence rate, effect estimate, change in air quality, and the affected population.		
SARS-CoV-2	Wang et al., 2021 (49) China	The aim of the study is to propose and evaluate a smart low-cost ventilation control strategy based on occupant-density-detection algorithm with consideration of both infection prevention and energy efficiency to prevent transmission of infection diseases, such as COVID-19, in public and private buildings, and to achieve a healthy yet sustainable indoor environment. **Methodology:** The study presents a smart ventilation control strategy that uses a camera-based occupant detection system with the YOLO algorithm for real-time detection. It compares three ventilation strategies: fixed, demand-controlled, and the proposed smart ventilation. The smart ventilation strategy dynamically adjusts airflow based on detected occupant density and calculated infection risk, aiming to optimize both energy efficiency and infection prevention. A low-cost hardware prototype is developed based on Raspberry Pi, and its	**HVAC systems (e.g. displacement, mixing systems)** **Intervention:** Fixed Ventilation Mode: Maintains a constant fresh air supply ratio (15%-30%), regardless of occupancy changes. Demand-Controlled Ventilation (DCV) Mode: Supplies fresh air based on occupancy demand, adjusting for the number of occupants present. **Key outcomes:** Infection probability	• Case studies show that, compared with a traditional ventilation mode (with 15% fixed fresh air ratio), the proposed ventilation control strategy can achieve 11.7% energy saving while lowering the infection probability to 2%. • The developed ventilation control strategy provides a feasible and promising solution to prevent transmission of infection diseases (e.g., COVID-19) in public and private buildings, and help to achieve a healthy yet sustainable indoor environment. • The smart ventilation strategy achieved a significant reduction in infection probability to 2% while saving 11.7% of energy compared to the fixed ventilation mode. • The DCV mode led to a 66.6% energy saving compared to the fixed ventilation mode. It also reduced the infection probability to 8.5%, which was 4% lower than the fixed ventilation mode. The DCV mode reduced the infection probability to 8.5%, which was 4% lower than the fixed ventilation mode.

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		effectiveness is evaluated through infection risk and energy consumption analysis. The feasibility of the smart ventilation system for infection prevention and energy efficiency is demonstrated, providing insights into optimizing ventilation strategies for healthy yet sustainable indoor environments.		
SARS-CoV-2	Ho et al., 2021 (57) China	To develop CFD simulations and methods to model the airflow, exposure, and probability of infection for the reported conditions at the Guangzhou restaurant (where an outbreak of COVID-19 occurred in January 2020). Different configurations of the air conditioning (direction and magnitude of air flow, percentage of fresh air supplied) and boundary conditions (e.g., temperature, pressure, humidity) were investigated to determine the sensitivity of the results to these parameters and processes. **Methodology:** CFD models were used to simulate expelled aerosol plume transport and dispersion and to perform comparative studies of exposure risks under various scenarios. Spatial and temporal simulations of the relative concentrations of the expelled pathogen (assumed to be uniformly distributed in the vapour plume) are compared and used to determine risks of	**HVAC systems (e.g. displacement, mixing systems)** **Key outcomes:** Probability of infection	• Simulations confirmed that poor ventilation and recirculation increased pathogen concentrations and probability of infection. • Increasing the fresh-air supply to the ventilation decreased the pathogen concentrations and probability of infection. Increasing the fresh-air percentage to 10%, 50%, and 100% of the supply air reduced the accumulated pathogen mass in the room by an average of ~30%, ~70%, and ~80%, respectively, over 73 min. The probability of infection was reduced by 11%, 37%, and 51%, respectively.

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		exposure and probability of infection		
SARS-CoV-2	Das et al., 2023 (67) India	This study aimed to determine the effects of several engineering controls on the removal rate per hour of these aerosols; and the estimated ACH in a fleet of passenger railcars under both static and dynamic conditions (i.e., when the train was stationary in the maintenance yard and moving, respectively), and to evaluate the effectiveness of the ventilation and air filtration systems in a range of representative conditions in reducing the probability of exposure. **Methodology**: The methodology employed in the study involves the use of a flexible Bayesian hierarchical model for estimating inhalation exposures. Additionally, the study utilized an equation developed by Fann et al. (2012) to estimate the annual number of adverse health outcomes in various scenarios, which considers the baseline incidence rate, effect estimate, change in air quality, and the affected population.	**Filters and filter ratings to use in a mechanical ventilation system** **Intervention:** The engineering controls of interest included the: the ratio of recirculated to fresh (i.e., outdoor) air (corresponding to two ventilation damper positions); particle filtration efficiency of two different MERV filters used in the HVAC system; and presence or absence of a portable HEPA cabin air purifier system. **Key outcomes:** Probability of exposure	• Increasing the efficiency of the HVAC filters in the railcar (i.e., upgrading from MERV-8 to MERV-13 rated filters) increased the removal rate of the smallest particles from the space, and reduced the probability of infection to SARS-CoV-2 viral particles. • While this was the only variable that had a statistically significant effect on aerosol removal rate, increasing filter efficiency comes at the cost of increased operating expenditures (energy expenditure to overcome increased pressure drop across a more efficient filter) and capital costs for system upgrades (replacing lower cost MERV-8 with higher cost MERV-13 filters). Thus, there is a 41% reduction in the probability of exposure when the filter is upgraded to a MERV-13 and a 50% reduction in the probability of exposure when the filter is upgraded to a MERV-13 and a HEPA air purifier is used in the cabin. • The median probability of exposure is 6 per 10,000 under standard conditions and the risk is unchanged with the introduction of a HEPA air purifier. The probability of exposure is reduced to 3.5 per 10,000 with the MERV-13, and further to 3 per 10,000 when there is a MERV-13 filter and a HEPA air purifier.
SARS-CoV-2	Xie et al., 2024 (73) Canada	The study investigates the impact of heat sources at varying temperatures on personal exposure to different ventilation strategies in a restaurant setting.	**Environmental conditions to target for optimal ventilation** **Intervention:** Effect of Heat Source Temperature. The study	Graphs only, no tables or full description of results • Authors conclude that the use of low-temperature heat sources can elevate the risk of infection by increasing the local vertical temperature gradient. In comparison to

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		It aims to understand the effect of a heat source between two people on cross-infection risk, whether the heat source affects personal exposure levels across different ventilation strategies, and which ventilation strategy is best for different restaurants. **Methodology**: The study employed a combination of numerical simulations and experimental validations to investigate the transmission of respiratory viruses, including SARS-CoV-2, in indoor environments, specifically restaurants. The methodology involved the use of tracer gases to simulate the transport of small particles exhaled by humans. The airflow within the restaurant setting was modeled using Computational Fluid Dynamics (CFD) software, which allowed for the analysis of different ventilation strategies and their impact on airborne transmission risk. The Wells-Riley model was utilized to assess the infection risk based on the airflow patterns identified through the simulations. To evaluate the effectiveness of different ventilation strategies, the study compared DV and MV under various conditions, including the influence of heat sources (e.g., the temperature of the food	examined how varying the temperature of the heat source between two human bodies affects the risk of cross-infection under both displacement and mixing ventilation strategies. **Key outcomes:** Infection Risk	no heat source, the risk increased by 190.9% and 99.6% for displacement and MV strategies, respectively. • Under mixing ventilation, both low-temperature and no heat sources showed lower infection risks when compared to DV. However, DV is found to be highly effective in reducing the risk of infection when using a high-temperature heat source, with only 12.3% of the infection risk observed in mixing ventilation.

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		served). The study also validated the CFD model with experimental data to ensure the reliability of the simulation results.		
SARS-CoV-2	Foat et al., 2022 (71) United Kingdom	This work aims to show whether the temperature or Relative Humidity (RH) effects reported for simpler models (analytical or more simplified CFD models) are still present when realistic room airflows are included, and exposures are calculated over 5 min timescales. The study is primarily focused on the fluid dynamics effects of a change in temperature and RH. **Methodology:** The study used computational fluid dynamics (CFD) modelling to simulate the dispersion of exhaled droplets from a coughing person in a mechanically ventilated room. It analyzed how temperature and humidity affect the transport and evaporation of respiratory droplets of different sizes. The model considered factors like droplet size distribution, evaporation rates, airflow patterns, and exposure levels to viral RNA copies under various scenarios involving different temperatures, relative humidities, and individual positions. The models were validated through experimental data and sensitivity analyses to ensure their reliability	**Environmental conditions to target for optimal ventilation**	
			Intervention: Different values of RH (30-50 and 70%) Different values of temperature (16-20-28°C) **Key outcomes:** exposure to SARS-CoV-2 virus (RNA copy·s·m^{-3})	**Relative Humidity:** In a mechanically ventilated room, with all the associated complex air movement and turbulence, increasing the RH may result in reduced airborne exposure. However, this effect may be so small that other factors, such as a small change in proximity to the infected person, could rapidly counter the effect. • In the 0–1 m analysis, volume the median exposure reduced from 3095 to 2647 copies·s·m^{-3} as the RH increased from 30% to 70%. Similarly, in the 1–2 m analysis volume, the reduction in the median exposure was 4179–2488 copies·s·m^{-3}, for the same increase in RH. • In the 1–2 m analysis volume, RH was considered an important factor to control for in the model and the reduction in log RNA exposure from 30% to both 50% and 70% RH was statistically significant. • However, in the 2–3 m analysis volume, there was minimal absolute change in the median exposure although the change from 30% to 70% RH (16–12 copies·s·m^{-3}) was statistically significant. • The changes in median exposure due to RH in the 0–1 and 1–2 m volumes are larger than the reduction in exposure when moving from the 0 to 1 m volume to the 1–2 m volume. However, the reduction in exposure when moving from the 1–2 and 2–3 m volumes is much greater than any changes due to RH. **Temperature:** The effect of temperature on the exposure was more complex, with both positive and negative correlations. Therefore, within the range of conditions studied here, there is no clear guidance on how the temperature should be controlled to reduce exposure. • Although a statistically significant increase is observed as the temperature increases from 16 to 28°C overall, the magnitude and direction of this change vary between volumes. • In the 0–1 and 1–2 m volumes, the increase to 28°C is statistically significant. However, for the 2–3 m analysis volume data, compared to a temperature of 16°C, there was a statistically significant decrease in exposure at both 20 and 28°C.

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		in predicting droplet dispersion and viral exposure in indoor environments.		• In the 0–1 m volume, the median exposure increases more than ten times (504–5890 copies·s·m^{-3}) from 16 to 28°C. In the 1–2 m volume, the increase is much smaller, 2602–3789 copies·s·m^{-3}. In the 2–3 m volume, the median exposure decreased from 19.8–13.5 copies·s·m^{-3}. • It is not clear whether the large increase in the median exposure in the 0–1 m volume, as temperature increases, is a true reflection of the size of the temperature-driven effect.
			Building/room designs and ventilation types in building designs	
SARS-CoV-2	Dong et al., 2022 (75) Germany	The study employed a comprehensive methodology to investigate the impact of building openings' design parameters on indoor virus infection rates, specifically in a kindergarten building setting. **Methodology:** The methods involve developing a parametric infection rate optimization model to analyze the dynamic association between building opening parameters and indoor virus infection rates. Simulation experiments are conducted using Grasshopper technology and a Genetic Algorithm program to examine changes in geometric parameters of building openings and their influence on virus concentration. A new model prioritizing air velocity over ventilation rate is introduced to analyze infection rate distribution. Computational Fluid Dynamics (CFD) and the Wells-Riley model are employed to understand the relationship between building opening parameters and infection rates.	**Intervention:** Optimization of Building Openings compared to Pre-optimization state of building openings, with the original design parameters of the kindergarten building, including the total number of existing building openings (23 window openings and 14 skylight openings). Parametric Optimization Model compared to traditional evaluation criteria used in previous studies, which primarily focused on ventilation parameters without direct consideration of building design parameters. **Key outcomes:** Infection rate	• The experiments demonstrated that after parameter optimization, the average virus infection rate in the indoor space could be reduced by 3%. By strategically adjusting the design parameters of building openings, it was possible to achieve a significant decrease in the average infection rate within the building, leading to a healthier indoor environment with lower risks of respiratory epidemic infections. • After the optimization of building openings, the study observed a significant decrease in the fluctuation of infection rate values within the space. The variance in infection rates decreased by 74.62%, 60.97%, and 44.72% compared to the pre-optimization values.

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SARS-CoV-2	Ren et al., 2022 (79) China	The aim of the study was to investigate the impact of window designs on airflow distribution and infection risk in the classroom, focusing on optimizing window openings and evaluating the effects of window-integrated fans to enhance ventilation efficiency and reduce infection probability. **Methodology:** an assessment of the ventilation efficiency in a selected educational building in Slovenia to calculate the transmission risks for COVID-19. This assessment includes an inspection of the building's ventilation systems, a review of mechanical installations, and measurements of various parameters such as the type of recuperation, surface area, height and volume of classrooms, air flow rate of the air-conditioning unit, and the type of air inlet. The study also utilizes the REHVA COVID-19 ventilation calculator, which is based on the Wells-Riley model, to determine the probability of infection for the selected space and human activity.	**Building/room designs and ventilation types in building designs**	
			Intervention: Optimization of Window Openings and Integration of Window-Integrated Fans. The study compares the effectiveness of various window opening modes, including the current mode and five renewed modes, in enhancing ventilation efficiency and reducing infection risk in a naturally ventilated classroom. Additionally, it evaluates the impact of installing window-integrated fans as a further intervention. **Key Outcomes**: Infection risk	**Optimization of Window Openings:** The study proposes and compares different configurations of window openings to assess their impact on ventilation efficiency and infection risk. Although specific numerical results are not provided in the provided text, the implication is that optimizing window openings can significantly affect airflow distribution, potentially enhancing ventilation efficiency and reducing infection risk in the classroom setting.
			Combinations of ventilation and filtration strategies	
			Intervention: Optimization of Window Openings and Integration of Window-Integrated Fans. The study compares the effectiveness of various window opening modes, including the current mode and five renewed modes, in enhancing ventilation efficiency and reducing infection risk in a naturally ventilated classroom. Additionally, it	**Implementation of Window-Integrated Fans:** • By installing fans at the windows, the study finds that ventilation efficiency is further enhanced, leading to a reduced infection risk. Authors concluded that both interventions—optimizing window openings and implementing window-integrated fans—can be effective strategies for improving ventilation in naturally ventilated classrooms, especially during transitional seasons with mild outdoor temperatures.

<table>
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<tr><td></td><td></td><td></td><td>evaluates the impact of installing window-integrated fans as a further intervention.

Key Outcomes:
Infection risk</td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Moritz et al., 2021 (76)

Germany</td><td rowspan="2">The aim of the study is to investigate the risk of transmitting SARS-CoV-2 during an experimental indoor mass gathering event under different hygiene practices, and to estimate the resulting burden of disease under conditions of controlled epidemics.

Methodology: The methods involve utilizing computational fluid dynamics to simulate particles distribution during a pop concert in Leipzig, Germany, with a focus on examining transmission pathways. An epidemiological model is employed to assess the event's impact on COVID-19 transmission, incorporating numerous factors such as control measures, contact types, testing strategies, and demographics. The methods also involve a comparison of different ventilation versions (VV1 and VV2) and scenarios. The goal is to provide insights into effective strategies for reducing SARS-</td><td colspan="2">Building/room designs and ventilation types in building designs</td></tr>
<tr><td>Ventilation version 1 (VV1) represented the current ventilation system in the arena. Here, the inlet air is blown laterally on the east and west sides by jet nozzles. The air supply was also carried out under the bleacher seats through rotational diffusers and under the mobile bleachers through ventilation grilles. The exhaust air was discharged at the corners of the stadium using exhaust towers. Air exchange per hour (ACH) was 1.46 h^{-1}, with a make-up air of 50 m3 h^{-1}-person.
Ventilation version 2 (VV2) To avoid large eddies, which generate intensified particles spread at face level, the jet nozzles and exhaust towers were turned off and the exhaust towers were replaced by exhaust pipes located under the</td><td>

The estimated mean number of exposed people per one infectious person was 3.5 (±2.9 standard deviation (SD)) in VV1, and 25.5 (±27.8 SD) in VV2 for Scenario 1, with a maximum of 10 and 108 exposed persons respectively.
The resulting additional average numbers of persons who would become infected and would be detected (excess cases) ranges from 5.1 under the strictest hygiene practice and best ventilation (Scenario 3, VV1) to 22.0 with no hygiene practice and non-optimal ventilation (Scenario 1, VV2) in the low incidence scenario (10 per 100,000 per week) and with spectators wearing masks. An increased incidence of 100/100,000/week results in 11.7 and 196.8 persons likely to acquire an infection during an MGE for the same conditions.

<table>
<tr><th rowspan="2"></th><th rowspan="2">IN</th><th rowspan="2">S</th><th colspan="2">Increase of SARS-CoV-2 positive cases [%]</th></tr>
<tr><th>No masks</th><th>Masks</th></tr>
<tr><td rowspan="9">Ventilation Version 1</td><td rowspan="3">10</td><td>1</td><td>13.3 [-43.7; 112.8]</td><td>13.3 [-45.4; 115.3]</td></tr>
<tr><td>2</td><td>11.3 [-46.8; 120.8]</td><td>11.6 [-45.3; 109.2]</td></tr>
<tr><td>3</td><td>7.7 [-45.9; 97.5]</td><td>9.2 [-46.9; 96.8]</td></tr>
<tr><td rowspan="3">50</td><td>1</td><td>9.2 [-19.7; 39.9]</td><td>5.0 [-20.5; 35.8]</td></tr>
<tr><td>2</td><td>5.1 [-21.0; 35.6]</td><td>3.7 [-23.2; 38.0]</td></tr>
<tr><td>3</td><td>2.6 [-22.9; 31.9]</td><td>1.4 [-26.7; 34.4]</td></tr>
<tr><td rowspan="3">100</td><td>1</td><td>9.1 [-11.1; 30.6]</td><td>4.8 [-14.2; 27.4]</td></tr>
<tr><td>2</td><td>4.8 [-14.4; 28.6]</td><td>2.8 [-16.7; 26.7]</td></tr>
<tr><td>3</td><td>2.3 [-17.3; 25.0]</td><td>1.2 [-17.6; 22.5]</td></tr>
<tr><td rowspan="9">Ventilation Version 2</td><td rowspan="3">10</td><td>1</td><td>29.2 [-40.3; 136.8]</td><td>18.7 [-43.5; 114.2]</td></tr>
<tr><td>2</td><td>15.6 [-44.2; 113.0]</td><td>11.0 [-47.2; 97.6]</td></tr>
<tr><td>3</td><td>11.2 [-47.0; 104.9]</td><td>8.3 [-47.3; 93.9]</td></tr>
<tr><td rowspan="3">50</td><td>1</td><td>24.6 [-8.1; 64.7]</td><td>12.6 [-15.4; 45.0]</td></tr>
<tr><td>2</td><td>11.7 [-16.1; 45.5]</td><td>6.5 [-20.5; 39.7]</td></tr>
<tr><td>3</td><td>5.3 [-21.8; 36.5]</td><td>2.2 [-23.0; 33.1]</td></tr>
<tr><td rowspan="3">100</td><td>1</td><td>23.6 [-0.2; 49.9]</td><td>12.2 [-10.1; 36.3]</td></tr>
<tr><td>2</td><td>10.8 [-9.7; 35.2]</td><td>6.2 [-12.3; 27.8]</td></tr>
<tr><td>3</td><td>4.5 [-14.5; 25.5]</td><td>2.3 [-16.2; 24.2]</td></tr>
<tr><td colspan="5">IN: incidences per 100,000 per week, Scenario 1-3</td></tr>
</table>
</td></tr>
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		CoV-2 transmission during indoor mass gatherings.	roof, resulting in an ACH of 0.85h^{-1}. **Scenario 1:** Pre-pandemic state. Participants entered and exited the arena through two main entrances without restrictions. They sat with no free seats in the middle. **Scenario 2:** Moderate hygiene measures were applied. The arena was divided into four quadrants. Participants entered and exited through the entrance/exit of the assigned quadrant (four entrances/exits) and could not change quadrants. A seating arrangement was implemented, occupying every second seat and alternating the rows (like a checkerboard pattern). **Scenario 3:** Further reduction in contact. Participants' seats were arranged in pairs, and a minimum distance of 1.5 meters was maintained between pairs of occupied seats. **Key outcomes:** Number of exposed people per one infectious	Author concluded that when hygiene practices are applied and the conditions of good ventilation are met, the mass gathering events appear to contribute little to the epidemic spread of COVID-19. A lack of hygiene practices and/or inadequate ventilation can increase the number of subjects at risk.

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

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<tr><td></td><td></td><td></td><td>Increase of SARS-CoV-2 positive cases</td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Zheng et al., 2021 (81)

Singapore</td><td rowspan="2">The aim of the study is to evaluate the effectiveness of natural ventilation and the dispersion pattern of gaseous pollutants between different units in a multi-storey building, driven by wind-induced natural ventilation, and to assess the inter-unit infectious risk in the worst unit (worker dormitories in Singapore) under different shading conditions using computational fluid dynamics simulations.

Methodology: The methods involve creating a geometric model of a multi-storey building with external shading louvers for Computational Fluid Dynamics (CFD) simulations. The computational domain and boundary conditions, including wind speed, direction, and temperature, are defined. Grid resolution and solver settings are determined to capture detailed airflow patterns and optimize simulation accuracy. The realizable k-ε turbulence model is selected after a sensitivity analysis. Numerical simulations are validated with experimental measurements.</td><td colspan="2">**Building/room designs and ventilation types in building designs**</td></tr>
<tr><td>**Intervention:**
Airflow Exchange and Pollutant Dispersion: The intervention here is the presence of external shading louvers. The comparators in this context would be the airflow and pollutant dispersion patterns in the absence of shading louvers or with different configurations (e.g., louver positions).
Inter-Unit Infectious Risk of COVID-19: the re-entry ratio of tracer gas and the airborne infection risk of COVID-19 in cases with different louver locations (windward vs. leeward) and source units, the comparators would be scenarios without shading louvers or with varying positions.

Key outcomes: Infection Risk</td><td>The study investigated the impact of external shading louvers on airflow characteristics, pollutant dispersion, and the risk of airborne infection in a multi-storey building, focusing on two main outcomes: the airflow exchange and pollutant dispersion through semi-shaded openings, and the inter-unit infectious risk of COVID-19.

Airflow Exchange and Pollutant Dispersion Interventions:
• The results showed that the airflow is commonly slower in the semi-shaded space between louvers and openings. However, the ventilation rate is not always consistent with the airflow speed due to the diversion effect from louver slats. This indicates that while louvers may slow down the airflow, they do not necessarily reduce ventilation effectiveness, which is crucial for pollutant dispersion.

Inter-Unit Infectious Risk of COVID-19 Interventions:
• The inter-unit infectious risk in the worst unit rises from 7.82% to 26.17% for windward shading, while it rises from 7.89% to 22.52% for leeward shading.</td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Luo et al., 2023 (25)</td><td rowspan="2">The aim of the study is to investigate the ventilation, expiratory droplet dispersion,</td><td colspan="2">**Numbers of air changes per hour (ACH) for optimal ventilation**</td></tr>
<tr><td>**Intervention:** Different configurations of open</td><td>The results are shown especially with graphs, but the authors reach the following conclusions:</td></tr>
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		and infection risk control in coach buses, particularly focusing on the effect of opening windows and wind catcher. The study aims to address the potential high-risk indoor environments for the transmission of respiratory diseases in coach buses due to high population density, complex and frequent population movements, and possibly inadequate ventilation. **Methodology:** The study employs a comprehensive computational fluid dynamics (CFD) modelling approach to simulate the outdoor wind flow and indoor airflow within a coach bus environment. The bus model is placed within a computational domain that allows for the simultaneous modelling of outdoor wind flow and indoor airflow. To accurately capture the airflow dynamics and droplet dispersion, the study utilizes refined grid arrangements within the computational domain. The simulation includes the dispersion of a tracer gas and the tracking of droplets to mimic the transmission of COVID-19. Boundary conditions and assumptions are applied to the simulations to model real-world scenarios accurately like bus	window positions and sizes. A wind catcher to the coach bus. the role of bus speed (30 km/h, 60 km/h, and 90 km/h) on natural ventilation. **Key Outcomes:** droplet transmission and potential infection risk. Tracer gas admission fraction (FIg) and droplets (IFd) are used to measure the potential infection risk of passengers.	• Open windows significantly improve natural ventilation, thus potentially reducing the risk of infection among passengers. Opening the front and rear windows can provide sufficient natural ventilation in the vehicle. The ACH at all windows ajar (146.37 h−1) is almost half of ACH when all windows open (293.36 h−1). It indicates that the ventilation rate is proportional to the area of the open window. • The wind collector has a great benefit in improving natural ventilation. Especially when the front windows are open, the ACH can increase almost 9 times compared to the situation without the wind collector (the ACH reaches 450.23 h−1, and the air age is only 6.21 s). Therefore, the wind catcher can affect the potential infection risk of passengers. • When the bus speed is 90 km/h, ACH is up to 448.86 h^{-1}. When the bus speed is 30 km/h, ACH is only 146.07 h^{-1}. Therefore, vehicle speed is an important factor affecting the natural ventilation of the cabin. The slower the vehicle speed, the lower the ACH, the higher the air age, the greater the potential risk of passenger infection.

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		speed, window configurations, and the use of a wind catcher.		
SARS-CoV-2	Shinohara et al., 2024 (86) Japan	The aim of the study was to determine the air exchange rates in commuter train cars under various conditions, understand the effects of potential countermeasures against COVID-19, evaluate the airborne infection risk of COVID-19 for passengers on commuter trains, and estimate the concentration of virus to which a passenger in a commuter train was exposed. **Methodology:** The study conducted comprehensive assessments of air exchange rates in Tokyo Metro Series 16000 commuter trains during different periods in 2020, focusing on the 3rd and 8th cars. A two-zone model was utilized to estimate COVID-19 transmission risk via inhalation of droplet nuclei, considering factors like virus emission rates and air flow volume rates. Air exchange rates were measured under different scenarios, including window openings, AC/fan operation, and train speeds. The infection risk for commuters was estimated based on these measurements, assumed community infection rates, commute time, and passenger numbers. Finally, the	**Combinations of ventilation and filtration strategies** **Intervention:** Window Opening: The intervention tested was the opening of windows to different degrees (0, 5, 10, 15, and 26.8 cm) to assess how varying degrees of window opening affect air exchange rates. The comparator in this scenario was the condition with windows completely closed. Door Opening: Involved opening all 4 doors on the same side of the car, compared to having all doors closed, to evaluate the impact on air exchange rates. Use of Air Conditioning (AC) and Crossflow Fan Systems: The intervention tested the effect of having centralized air conditioning and crossflow fan systems either turned on or off. The comparator was the opposite state of the systems (on vs. off)	• Implementing the intervention of turning on the AC/fan and opening windows resulted in a significant reduction in the risk of COVID-19 infection. • The infection risk of a passenger within 50 cm in front of a talking infected person when a single infected person is in the car (Rnear_1) carrying 150 passengers travelling for 30 min in the context of a community infection rate of 0.30% is 8.5×10^{-5} with the windows closed and AC/fan off, however dropped to 5.0×10^{-6} with the window open and AC/fan on. • The estimated infection risks in a train car (R_{train}), carrying 150 passengers for 30 min at a community infection rate of 0.30%, with closed window and AC/fan off were reduced from 2.5×10^{-8} when the infected persons were silent and 1.5×10^{-7} when the infected persons were talking to 1.7×10^{-9} and 1.1×10^{-8}, respectively, when all 12 windows were open to 10 cm and the AC/fan was on. • Assuming that 30–300 passengers traveled on trains for 7–60 min in the context of a community infection rate of 0.0050–0.30%, the risk of airborne infection risk in a train car (R_{train}) was estimated to be reduced by 91–94% when windows were open (12 windows each open to 10 cm), and the AC/fan was on compared with when windows were shut, and the AC/fan was off. In the supplementary material, the authors provide a table with the risk of infection according to community infection rate, commute time, number of passengers, infected persons are silent or talking, and the combination of window and fan on or off.

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<tr><td></td><td></td><td>study compared the infection risk reduction when all windows were opened, and the AC/fan was on versus when windows were closed, and the AC/fan was off to evaluate the effectiveness of ventilation strategies in reducing infection risk.</td><td>AC/Fan On, Windows Open compared to AC/Fan Off, Windows Closed.

Key outcomes: Infection Risk</td><td></td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Sha et al., 2024 (85)

Canada</td><td rowspan="2">The study focused on optimizing building ventilation to minimize COVID-19 risk and maximize energy efficiency. It introduced a new strategy that balances energy consumption and indoor air quality.

Methodology: The study presents a methodology using a modified Wells-Riley model to calculate a safe ventilation rate that minimizes COVID-19 infection risk, considering factors like social distancing, mask usage, and initial infection rates. It aims to optimize ventilation rates for reducing COVID-19 transmission risk and maximizing energy savings in buildings. The energy performance of mechanical ventilation systems is evaluated through nine proposed cases, including a baseline and variations with different settings. These cases consider factors like specific fan power, fan flow rates, and ventilation control strategies. A case study of a high-rise building in Montreal,</td><td colspan="2">**Combinations of ventilation and filtration strategies**</td></tr>
<tr><td>**Intervention:** Dilution Ventilation and Ventilative Cooling (DVVC)
Intervention 1: DVVC Control Strategy
Comparator: Baseline case without the DVVC control strategy.
Intervention 2: DVVC + LSFP (Low Specific Fan Power)
Comparator: DVVC control strategy without the consideration of low specific fan power.
Intervention 3: DVVC + LSFP + Variable Fan Flow Rates (F2 ~ F6)
Comparator: DVVC + LSFP without variable fan flow rates.
Intervention 4: DVVC + LSFP + Optimal Fan Flow Rate (F6)</td><td>Graphs only, no tables or full description of results.
The COVID-19 infection risk in DVVC shows that the existing fan flow rate (35.7 m3/s, 0.8 ACH) is not high enough to reduce the infection risk of COVID-19 to lower than 1% at all times. For example, the infection risk of COVID-19 in DVVC can achieve 1.5% at the peak occupancy rate in 08/26, but the ventilation rate is at maximum and cannot further reduce the infection risk.</td></tr>
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		Canada, is included to demonstrate the impact of the proposed ventilative cooling control strategy on reducing transmission risks and energy consumption.	Comparator: DVVC + LSFP with non-optimal fan flow rates. Intervention 5: VCO (Ventilative Cooling Only) Comparator: DVVC control strategy without exclusive focus on ventilative cooling. **Key outcomes:** Infection Risk	
SARS-CoV-2	Tognon et al., 2023 (88) Italy and Finland	The aim of the study is to evaluate the performance of hybrid ventilation systems in residential and educational buildings, focusing on their impact on energy consumption, indoor air quality, and the risk of airborne infection from COVID-19. **Methodology:** The paper presents a co-simulation approach to evaluate control strategies for hybrid ventilation systems in a residential and an educational building. Using simulation tools CONTAM and TRNSYS, the study models ventilation systems and assesses strategies to optimize ventilation effectiveness and energy efficiency. The focus is on indoor air quality and COVID-19 infection risk. The simulations	**Combinations of ventilation and filtration strategies**	
			Intervention: Baseline (Case A): A balance between natural ventilation (NV) and mechanical ventilation (MV) based on external temperature and occupancy. NV Dominant (Case B): Preference for natural ventilation over mechanical, adjusting control parameters to extend NV periods. MV Dominant (Case C): Preference for mechanical ventilation, modifying temperature controls to favor MV operation. **Key outcomes:** Airborne Infection Risk from COVID-19	**Enhanced Natural Ventilation (NV Dominant - Case B)** Results for the apartment show that different control strategies do not lead to significant variations in the overall heating demand for a given climate. In contrast, increasing natural ventilation hours during the cooling season produces savings in both sensible (up to 31% in Venice) and latent demand (up to 30% in Rome). Fan absorption in the heating season is reduced by 40% and 86% in Rome for the flat and classroom, respectively and by 84% in Venice for the apartment in the cooling season. Moreover, a control strategy enhancing natural ventilation is promising in reducing the infection risk. Therefore, if well-regulated through a suitable control strategy, the hybrid ventilation system seems promising in maintaining healthy indoor environments while reducing energy consumption. **Increased Mechanical Ventilation (MV Dominant - Case C)** Resulted in the highest infection risk levels due to lower ventilation flow rates compared to the baseline and NV dominant scenarios. To achieve similar risk mitigation as in the NV dominant system, the supply flow rates in the MV dominant scenario would need to be increased, which would also raise the energy demand for air handling. **Baseline Scenario (Case A)** This scenario often resulted in days where both ventilation modes could occur, leading to intermediate risk values. The baseline scenario serves as a middle ground, indicating that a balance between natural and mechanical ventilation without specific enhancements does not optimize energy efficiency or minimize infection risk as effectively as the NV dominant strategy.

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

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		consider seasonal heating and cooling demands and electrical consumption for air handling. The study provides a detailed analysis of how different ventilation scenarios impact energy demand, infection risk, and indoor environmental quality, aiming to identify configurations that reduce energy consumption and mitigate infection risk.		
			Combinations of ventilation and filtration strategies	
SARS-CoV-2	Cai et al., 2022 (83) United States	The aim of the study is to evaluate the HVAC energy costs for reducing COVID-19 airborne infection risks in public and private schools in the U.S. under different intervention scenarios, integrating infection risk modelling and energy consumption simulation, to provide operational guidelines, financial implications, and policy insights for schools, community stakeholders, and policymakers to keep schools safe during the ongoing pandemic and improve preparedness for future epidemics. **Methodology:** The study modeled the energy costs for school HVAC (Heating, Ventilation, and Air Conditioning) systems, considering the energy required for heating, cooling, and fan operation. This was done for over 100,000 public and private	**Intervention:** Ventilation Rate Increase with Air Filtration: This intervention involved increasing the ventilation rates in schools and implementing air filtration using e MERV-13 filters. **Key Outcomes:** infection risk control	They do not provide reporting or description of numerical data of ventilation rates, only graphs. • Modelling results show that PK-5 (prekindergarten and elementary) schools can limit the infection risk below 1% by modestly increasing ventilation rates with air filtration. • In contrast, the 1% infection risk could not be achieved in middle and high schools without unrealistically high ventilation rates even with the use of air filtration. • The results indicate that these schools may consider additional infection control measures such as de-densification by implementing partial online learning to maintain infection risk at acceptable levels and lower the required ventilation rates to save energy costs. These required ventilation rates under different scenarios serve as the ventilation schedule to compute the energy cost for schools.

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		schools across the U.S. Different strategies to limit infection risk were evaluated, focusing on their impact on ventilation rates and energy costs. Strategies included improving ventilation with air filtration and implementing partial online learning.		
SARS-CoV-2	Zafarnejad & Griffin, 2021 (89)	The study aimed to evaluate the effectiveness of non-pharmaceutical interventions (NPIs), including social distancing, ventilation upgrades, surveillance testing, and contact tracing, in reducing the transmission risk of SARS-CoV-2 in school settings. **Methodology:** The methodology involves developing an agent-based simulation model to simulate the spread of SARS-CoV-2 in closed classroom environments. It incorporates factors like local quanta spread, student behavior compliance, and policy actions, extending traditional transmission models to include these factors and non-uniform air mixing. The impact of Non-Pharmaceutical Interventions (NPIs) on transmission risk is assessed under various scenarios and policy actions. The effectiveness of NPIs such as social distancing, ventilation upgrades, surveillance testing, and contact tracing is evaluated.	**Combinations of ventilation and filtration strategies**	
			Intervention: Social Distancing, High-Quality Air Filtration and Ventilation, Surveillance Testing, and Contact Tracing vs. Lack of These Interventions **Key outcomes:** Transmission risk (reduction in the relative mean transmission risk %)	• Ventilation and air filtration: reduction in the relative mean transmission risk > 28% (M = 28.44, SD = 11.27) Comparing IVRR = 1 vs 2.2 Author concluded that ventilation and air filtration intervention reduce the mean transmission risk by 25%. This indicates that while changes to ventilation can significantly impact the reduction of transmission risk in closed environments such as classrooms.

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		Parameters like the infectious virus removal rate (IVRR) are used to calculate infection risk. Simulations are run for different scenarios, including variations in class schedules, durations, ventilation rates, and contact tracing levels.		
SARS-CoV-2	Corzo et al., 2022 (62)	The aim of the study was to investigate the airborne transmission of COVID-2 in urban buses with twenty seated passengers to evaluate the effectiveness of different airflow and air renewal conditions in reducing the transmission risk. **Methodology:** The study employed computational fluid dynamics (CFD) simulations to investigate the ventilation and virus propagation in an urban bus under various scenarios. These scenarios included different states of window openness (closed windows, open windows) and the operation status of the Heating, Ventilation, and Air Conditioning (HVAC) system (HVAC on/off). The study utilized a combination of analytical and computational models to simulate virus transmission in a bus with reduced seating capacity, focusing on the impact of the HVAC system's operation with air recirculation on virus spread.	**HVAC systems (e.g. displacement, mixing systems)** **Interventions**: Four scenarios were considered: HVAC off with closed windows (Case 1), HVAC on with closed windows and 100% of air recirculation (Case 2), HVAC on with closed windows and 75% of air recirculation (Case 3), and HVAC off and the bus moving at 20 km/h with some windows opened (Case 4). **Key Outcomes**: reducing virus concentration and transmission risk.	• HVAC off with closed windows (Case 1) (this serves as the baseline scenario for comparison with other interventions where ventilation strategies are applied): This scenario resulted in almost negligible airflow motion, leading to low air mixing and potentially higher virus concentration due to limited dispersion. • HVAC on with close windows and 100% of recirculation: Different to Case 1, in the second, the strong airflow removes the exhaled gas far from the emitters, reducing their subsequent inhalation and causing more virus to be effectively delivered into the bus. On the other hand, due to the fast dissemination, a significant fraction of the virus is inhaled by all of them, reducing the average concentration. The HVAC has a clear benefit reducing the local risk below 3% for any occupants. • HVAC on with closed windows and 75% of recirculation (Case 3): The introduction of HVAC with 75% recirculation significantly reduced the maximum virus concentration by ten times compared to Case 2 after 10 minutes. The improvement by renewing 25% of the recirculated air was quite significant. The maximum risk remained below 1.2% (less than half that obtained with 100% recirculation). • HVAC off with some windows opened (Case 4): Opening windows resulted in the lowest average virus concentration among the scenarios, making it the safest option. The airflow patterns were more complex due to the interaction between internal and external flows, but effectively reduced virus concentration: the risk of transmission remained less than 0.1%, which is low to be considered negligible.

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SARS-CoV-2	Srivastava et al., 2021 (87)	The aim of the study is to assess the infection risk for susceptible people in a large office building under different ventilation/disinfection strategies during the COVID-19 pandemic. **Methodology:** The studies mentioned employ a combination of Computational Fluid Dynamics (CFD) simulations and the Wells-Riley equation to assess the infection risk of susceptible individuals in indoor environments, specifically large office buildings, in the context of the COVID-19 pandemic.	**Combinations of ventilation and filtration strategies**	
			Intervention: ventilation system without UV-C RM3 units, with only 10% outside air and 90% recirculated air without additional filtration. This case served as a reference. Case B: Operates with 100% outside air, without recirculated air or additional disinfection devices. Case C: Like Case A, but 36 RM3 UV-C units are added with a disinfection efficiency of 99.9% for SARS-CoV-22. These units provide additional clean air to the building. Case D: Combines 100% outside air with the 36 UV-C RM3 units, maximizing both ventilation and air disinfection. **Key Outcome:** infection risk probability for each person in the modeled office building environments.	**Use of 100% Outdoor Air:** The introduction of 100% outdoor air (Case B) aimed to reduce the concentration of SARS-CoV-2 by diluting indoor air with outdoor air. However, specific quantitative results comparing Case A directly to Case B in terms of infection risk reduction are not provided in the cited text. The effectiveness of this intervention is implied to be less than that of using RM3 UV-C units based on the comparison between Case C and Case D with Case A and B. **Use of RM3 UV-C Units:** The implementation of 36 RM3 UV-C units (Case C) significantly reduced the average infection risk probability from 26.99% in Case A to 2.23% in Case C. This demonstrates a substantial decrease in infection risk by 24.74% due to the disinfection efficiency of the RM3 UV-C units. **Combination of 100% Outdoor Air and RM3 UV-C Units:** Case D, which combines 100% outdoor air with 36 RM3 UV-C units, was compared to the other scenarios. While specific numerical results for Case D are not directly provided, it is implied that this combination would offer the most significant reduction in infection risk, building upon the individual benefits observed in Cases B and C. The effectiveness of Case D can be inferred to surpass that of using either intervention alone, given the substantial reduction in infection risk observed in Case C and the additional benefits of increased outdoor air as seen in Case B.
SARS-CoV-2	Foster & Kinzel, 2021 (84)	The aim of the study is to systematically evaluate mitigation strategies for SARS-CoV-2 transmission in classroom settings. Computational fluid dynamics simulations are used to	**Combinations of ventilation and filtration strategies**	
			Intervention: Ventilation Systems: Different types of ventilation systems were evaluated, including those	**College classroom:** • The highest risk and variability in transmission rates are the classroom settings that lack ventilation and any mitigation method (~25% mean with peak routes >40%).

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
		analyze the effectiveness of different approaches, such as the use of face coverings, varied ventilation schemes, air purifiers, and desk shields in thermally controlled classrooms. **Methodology:** The methods involve using Computational Fluid Dynamics (CFD) simulations to assess the efficacy of different strategies, such as face masks, various ventilation systems, air purifiers, and desk shields. The Wells-Riley model is incorporated to calculate the likelihood of transmission under varying conditions, considering factors like age and the Delta variant. Different ventilation systems, including those with MERV-11 and MERV-7 filters, and a range of air purifier configurations, such as single and double clean air curtain models, are evaluated.	with MERV-11 filters (standard in conventional classrooms) and MERV-7 filters (standard in portable classrooms). The study compared these against scenarios with less effective or no ventilation systems. Air Purifiers: The study assessed the effectiveness of different configurations of air purifiers, including a single air purifier based on the clean air curtain model, two clean air curtain air purifiers doubling the rate, and a single, conventional air purifier with double the capacity of the clean air curtain. These were compared against scenarios without air purifiers. Combination of Mitigation Strategies: The study also evaluated the combined effect of using multiple mitigation strategies (e.g., face coverings, desk shields, and air purifiers) against scenarios where fewer or no interventions were applied.	• This is followed by a group that has active ventilation (~16% mean with peak routes >30%), which is relatively independent of heating, cooling, or the filter MERV-7 or 11 ratings. • The lowest transmission probability grouping combines mitigation strategies with a combination of face coverings, ventilation, and various air purification strategies (3%–5% mean, peak 8%). • In general, viral particles entrained into the HVAC do not lead to increased probability routes as the HVAC leads to improved mixing and more uniform distribution of viral particles in addition to the filtration. **Elementary classroom:** • The mean and median risk from a non-ventilated elementary classroom without any other protocols was lower than the college classroom with the highest number of protocols. • The results showed that improved ventilation systems contribute to a lower transmission probability, underscoring the importance of adequate ventilation in reducing viral spread. • The results indicated that the strategic use of air purifiers, especially in configurations that enhance their effectiveness, can significantly reduce the transmission probability. Authors concluded that a combination of interventions is more effective in reducing transmission probabilities than individual measures alone. However, the study noted that using more than seven mitigation measures did not provide additional benefits and might need reconsideration in the context of more transmissible variants like the Delta variant.

RIDs	Reference Year/ Country	Objective / Methods	Interventions /Outcomes /Scenarios	Summary of Findings
			Key outcomes: transmission probabilities for the baseline SARS-CoV-2 and the Delta variant.	

Abbreviations: CFD = computational fluid dynamics; CO_2 = carbon dioxide

Table 3: Summary of studies reporting on effectiveness of VAFD in reducing the concentration of infectious particles in the air (n=2)

Last updated March 28th 2024

RIDs	Author Year/ Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
SARS-CoV-2	Horve et al., 2022 (42) United States	Isolation dorm rooms housing residence hall students that tested positive for COVID-19. University of Oregon January and May 2021	**HVAC systems (e.g. displacement, mixing systems)**		
			Design: Cohort. To assess the potential impact of window operations on the aerosolized viral load present within the study participant's rooms, study participants were asked the status of their room windows during the previous sampling period and researchers observed current window operation status at each entry. Samples were split into two groups consisting of (i) the window was open for more than 50% of the sampling period or (ii) the window was open for less than 50% of the sampling period. **Intervention:** Window operations. **Sample:** 17 males and 18 females between the age of 18 and 24. **Key Outcomes:** detectable viral load	Samples from particles collection methods (AerosolSense and passive settling plates) demonstrated a significant increase in CT values (correlating with a decrease in viral load) when the window was open for more than 50% of the sampling period. These results suggest that the increased ventilation that is provided from an open window could reduce the detectable viral load in the room by half when windows are open ($\bar{x}$=34.4) compared to when the windows are closed ($\bar{x}$=33.2). Limitations: The condition of the windows was taken from a questionnaire (self-report). Symptom and window position results are largely based on self-reported survey data, which may suffer from inconsistencies and misclassification bias. Some demographic aspects that may be considered confounders are described, but there is a lack of details regarding adjustments for other potentially confounding variables.	Critical
			Numbers of air changes per hour (ACH) for optimal ventilation		
			Design: Cohort. The study used linear mixed models and Student's t-tests to analyze changes in viral load over time and found that symptoms, ventilation, and room ventilation play significant roles in the spread of the virus. **Intervention:** ACH flow rate. The room air is supplied from either the building common areas (via	ACH from mechanical exhaust in the isolation rooms was found to be significantly and positively related to observed CT values ($P < 0.01$), with increased ACH in the room more likely to produce higher CT values. However, a significant decrease in the percent positivity of aerosol samples was not observed ($P=0.43$) as ACH increased across study rooms. Even across a fairly narrow range of ACH, increased ventilation rate decreases the detectable aerosolized viral load within enclosed spaces. However, the lack of decrease in percent positivity suggests that the modest range of ACH values found in this study is	Moderate

RIDs	Author Year/ Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
			a roof-top unit supplying 100% outside air) or the dormitory room windows. **Sample:** 17 males and 18 females between the age of 18 and 24. **Key Outcomes**: positivity of aerosol sample	not enough to decrease the abundance of viral particles in the enclosed space to an undetectable level. Limitations: For the evaluation of the different air renewal rates (ACH), the methods used were objective, however the RoB remains with respect to possible confounding factors.	
SARS-CoV-2 Alpha (B.1.1.7), Iota (B.1.526), Gamma (P.1), and Delta (B.1.617.2) SARS‐CoV‐2 variants	Myers et a., 2022 (70) United States	**Homes** of adults who had received a positive clinical test within the last 7 days. The study was conducted in New Jersey, USA. November 2020 and May 2021	**Portable air cleaners**		
			Design: the study was a randomized crossover trial using air filtration with PACs as the intervention. Sampling was conducted in participants' residences for two consecutive 24-h periods (Day 1 and Day 2). **Intervention**: portable air cleaners (PAC) operated in "filtration" (HEPA filter installed) or "sham" (HEPA filter removed) modes. **Sample**: 17 houses of patients diagnosed with Covid-19. **Key Outcomes:** presence of SARS-CoV-2 RNA in the air at infected persons' homes	• Seven out of sixteen (44%) air samples in primary rooms were positive for SARS‐CoV‐2 RNA during the sham period. With the PAC operated at its lowest setting (clean air delivery rate [CADR] = 263 cfm) to minimize noise, positive aerosol samples decreased to four out of sixteen residences (25%; p = 0.229). • During the "filtration" period, two of the four bedrooms with positive aerosol samples in the "sham" period had negative aerosol samples (50% decrease; p = 0.310), even though these two participants reported spending close to 24 h in the bedrooms. • One of the three living rooms, where viral RNA was detected in the air during the "sham" period, tested negative during the "filtration" period (33.3% decrease; p = 0.500), even though the participant occupied it for 14 h. • For the "filtration" period, one of the four bedrooms with positive aerosol samples in the "sham" period tested negative (25% decrease; p = 0.500); this participant spent 8 h in the bedroom. However, the effect of PAC was not observed for the other rooms (no reduction in the number of positive aerosol samples; n = 3; p = 0.686). Authors concluded that the presence of airborne viral RNA might be reduced by using PACs. Despite the	High

RIDs	Author Year/ Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
				study's limited sample size, its findings can begin to inform public health measures to minimize COVID‐19 transmission in residences and support the need for robust trials of PACs. Limitations: In this study, the main concerns are about the very small sample size, the reporting of an imputed case, multiple uncontrolled confounding factors and no statistical adjustment. Data with which the new period begins is not reported, the results are grouped and there is no washing time.	
Evidence gaps					
No data yet	Filters and filter ratings to use in a mechanical ventilation system /Environmental conditions (e.g. temperature and humidity) to target for optimal / Building/room designs (e.g. number and position of mechanical air supplies, exhausts, windows, and doors) and ventilation types in building designs (e.g. cross ventilation, single-sided ventilation)/ Combinations of ventilation and filtration strategies				

Abbreviations: ACH = air changes per hour; aOR = adjusted odds ratio; CDC = Centres for Disease Control; CI = confidence interval; HEPA = high-efficiency particulate absorbing; IQR = interquartile range; lg = large; MVS = mechanical ventilation system; OR = odds ratio; PCR = polymerase chain reaction; RR = rate ratio; RRR = relative risk reduction; sm = small; UVGI = ultraviolet germicidal irradiation

Table 4: Summary of modelling studies reporting on effectiveness of VAFD in reducing the concentration of infectious particles in the air (n=5)

Last updated March 28th 2024

<table>
<tr><th>RIDs</th><th>Reference Year / Country</th><th>Objective / Methods</th><th>Intervention / Outcome / Scenarios</th><th>Summary of Findings</th></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Jones et al., 2021 (43)

United Kingdom</td><td rowspan="2">The aim of the study is to propose an analytical model to estimate uncertainty in the relative exposure to RNA copies in the air for a range of indoor spaces and ventilation and occupancy scenarios during a pandemic. The paper discusses a mathematical model and statistical framework to estimate the risk of exposure to SARS-CoV-2 through airborne aerosol transmission in various indoor scenarios. Factors such as ventilation rates, occupancy, respiratory rates, and removal mechanisms are considered to assess exposure risk.

Methodology: The methodology employed involves developing an analytical model to predict the number of viral genome copies (RNA copies) inhaled over a time period in an indoor space. This model is implemented to investigate a range of scenarios and spaces using Excel spreadsheets and bespoke MATLAB code. A mass-balance model is central to this approach, which is used to</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>**Intervention:**
Ventilation Rate Adjustment in Classrooms. Four different per capita ventilation rates were compared: 1.2, 3.4, 9.2, and 15.7 liters per second ($l\ s^{-1}$) per person.

Key outcomes:
Relative Exposure Index (REI) to viral particles</td><td>**Ventilation Rate Adjustment in Classrooms:**
• Four different per capita ventilation rates were compared: 1.2, 3.4, 9.2, and 15.7 liters per second ($l\ s^{-1}$) per person. These rates were chosen to achieve maximum mean CO_2 concentrations of 5000, 2000, 1000, and 750 parts per million (ppm), respectively.
• The study found that the poorest ventilated classroom, with a ventilation rate of $1.2\ l\ s^{-1}$ per person (leading to 5000 ppm CO_2), had a REI of 2.33, indicating a very large effect size compared to the reference scenario. Conversely, increasing the ventilation rate to $15.7\ l\ s^{-1}$ per person (leading to 750 ppm CO_2) significantly reduced the REI to 0.38, demonstrating the clear benefits of enhanced ventilation.

Reduced Airflow Rate in High Emitting Spaces:
The study compared the effect of reducing the airflow rate to 2 liters per second ($l\ s^{-1}$) per person in high emitting spaces, without specifying a direct comparator in terms of airflow rate but implying the comparison is against the reference classroom scenario or better-ventilated conditions.
• Reducing the airflow rate to $2\ l\ s^{-1}$ per person increased the REI to 1.63.

Table 4 Relative exposure index for common spaces and high emission scenarios.
<table>
<tr><th>Scenario</th><th>$P_{2.5}$</th><th>P_{25}</th><th>P_{50}</th><th>P_{75}</th><th>$P_{97.5}$</th><th>□</th><th>□</th><th>C□ (%)</th><th>Cohen's d</th><th>Effect size</th></tr>
<tr><td>Reference scenario</td><td>0.45</td><td>0.77</td><td>1.00</td><td>1.30</td><td>2.05</td><td>1.06</td><td>0.41</td><td>39</td><td></td><td></td></tr>
<tr><td>Class 750</td><td>0.17</td><td>0.29</td><td>0.38</td><td>0.50</td><td>0.78</td><td>0.41</td><td>0.16</td><td>39</td><td>2.09</td><td>Very large</td></tr>
<tr><td>Class 1000</td><td>0.28</td><td>0.47</td><td>0.62</td><td>0.80</td><td>1.25</td><td>0.66</td><td>0.25</td><td>39</td><td>1.19</td><td>Large</td></tr>
<tr><td>Class 2000</td><td>0.59</td><td>1.00</td><td>1.31</td><td>1.68</td><td>2.71</td><td>1.39</td><td>0.55</td><td>39</td><td>-0.68</td><td>Medium</td></tr>
<tr><td>Class 5000</td><td>1.02</td><td>1.77</td><td>2.33</td><td>3.02</td><td>4.84</td><td>2.49</td><td>1.00</td><td>40</td><td>-1.86</td><td>Very large</td></tr>
<tr><td>Office</td><td>0.43</td><td>0.75</td><td>0.98</td><td>1.28</td><td>2.07</td><td>1.05</td><td>0.43</td><td>41</td><td>0.03</td><td>Negligible</td></tr>
<tr><td>Office Low</td><td>0.67</td><td>1.22</td><td>1.63</td><td>2.16</td><td>3.55</td><td>1.76</td><td>0.75</td><td>43</td><td>-1.14</td><td>Large</td></tr>
<tr><td>Coffee</td><td>0.02</td><td>0.03</td><td>0.04</td><td>0.05</td><td>0.08</td><td>0.04</td><td>0.02</td><td>38</td><td>3.48</td><td>Very large</td></tr>
<tr><td>Coffee Low</td><td>0.03</td><td>0.05</td><td>0.06</td><td>0.08</td><td>0.12</td><td>0.07</td><td>0.03</td><td>39</td><td>3.40</td><td>Very large</td></tr>
<tr><td>Supermarket (X10-3)</td><td>0.45</td><td>0.77</td><td>1.01</td><td>1.30</td><td>2.05</td><td>1.07</td><td>0.41</td><td>39</td><td>3.63</td><td>Very large</td></tr>
<tr><td>Gym</td><td>0.64</td><td>1.09</td><td>1.42</td><td>1.84</td><td>2.94</td><td>1.52</td><td>0.59</td><td>39</td><td>-0.88</td><td>Large</td></tr>
<tr><td>Guangzhou</td><td>0.30</td><td>0.52</td><td>0.68</td><td>0.88</td><td>1.44</td><td>0.73</td><td>0.29</td><td>40</td><td>0.95</td><td>Large</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year / Country</th><th>Objective / Methods</th><th>Intervention / Outcome / Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td>investigate the number of RNA copies contained in particles transported to and from an indoor space. The model assumes that RNA copies are generated at a single point at a constant rate and are mixed rapidly so that the change in the number of RNA copies in the space, with time, is approximately the same regardless of the sampling point. The number of RNA copies in the space is diluted by a number of mechanisms that can be normalized by the volume of the space and combined into a single removal rate by addition. A statistical modelling framework is described in the Supplementary Materials and is used to quantify uncertainty in the relative exposure associated with a space.</td><td></td><td>
<table>
<tr><td>Skagit Choir</td><td>5.26</td><td>9.42</td><td>12.56</td><td>16.50</td><td>26.63</td><td>13.45</td><td>5.53</td><td>41</td><td>-3.16</td><td>Very large</td></tr>
<tr><td>German Meeting</td><td>2.75</td><td>5.14</td><td>7.00</td><td>9.37</td><td>16.12</td><td>7.62</td><td>3.47</td><td>46</td><td>-2.65</td><td>Very large</td></tr>
</table>
The columns represent different percentiles (P2.5, P25, P50, P75, P97.5), the mean (μ), standard deviation (σ), coefficient of variation (Cv %), Cohen's d, and the effect size for each scenario.

The table shows that scenarios with poor ventilation or high emission activities (e.g., singing in the Skagit Choir scenario) have higher REIs and very large effect sizes, indicating significant exposure risks. Conversely, scenarios with better ventilation or lower emission activities have lower REIs and smaller or negligible effect sizes, suggesting reduced risks.</td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Riediker et al., 2020 (44)

Switzerland</td><td rowspan="2">The study aimed to determine the potential exposure to SARS-CoV-2 in a room shared with individuals at diverse levels of COVID-19 severity. By combining mathematical modelling with data on viral swab and sputum concentrations, the study sought to provide insights into the emission of viral particles and the associated infection risks in indoor environments</td><th colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</th></tr>
<tr><td>Intervention: different air exchange rates in an enclosed space: 1, 3, 10, and 20 times per hour.

Key outcomes: Viral load concentration</td><td>

The concentration of viral load was estimated between 0 to 80 minutes for the different air exchange rates. But no specific data is reported for each moment.
For a typical hospital ventilation situation of 10 air exchanges per hour, the concentration plateaus after approximately 30 minutes, while for a typical office with 3 air exchanges per hour, concentrations continue to increase for more than 1 hour.

Authors conclude that the viral load in the air can reach critical concentrations in small and poorly ventilated rooms, especially when the individual is a superspreader, defined as a person emitting large number of microdroplets containing a high viral load.

<table>
<tr><th colspan="5">Plateau Concentration for Different Combinations of Air Exchange Rate, Emission Form, and Emitter Type</th></tr>
<tr><td colspan="5">Air exchange rate, times/h</td></tr>
<tr><td>Measure</td><td>1</td><td>3</td><td>10</td><td>20</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year / Country</th><th>Objective / Methods</th><th>Intervention / Outcome / Scenarios</th><th>Summary of Findings</th></tr>
<tr><td></td><td></td><td>with varying ventilation conditions.

Methodology: The study employed a mathematical modelling approach to estimate the viral load in the air released by individuals with COVID-19, ranging from asymptomatic to moderate cases. The methodology focused on two primary activities: breathing and coughing, as these are common ways the virus can be expelled into the air. The model considered several key factors, including the viral load present in individuals, the volume of air in a room, the rate of air exchange (ventilation), and the formation of microdroplets, which can carry the virus and remain suspended in the air. By integrating these variables, the study aimed to quantify the concentration of virus copies per cubic meter of air under different conditions, such as varying levels of ventilation and the presence of coughing, which can significantly increase the emission of viral particles.</td><td></td><td>
<table>
<tr><td>Time until 99% of plateau, min</td><td>169</td><td>77</td><td>26</td><td>14</td></tr>
<tr><td colspan="5">Airborne viral concentration at plateau, copies/m3</td></tr>
<tr><td colspan="5">Regular breathing</td></tr>
<tr><td>Low emitter</td><td>0.000009598</td><td>0.000004310</td><td>0.000001472</td><td>0.000000758</td></tr>
<tr><td>Typical emitter</td><td>0.009598</td><td>0.004310</td><td>0.001472</td><td>0.000758</td></tr>
<tr><td>High emitter</td><td>1247.7</td><td>560.3</td><td>191.3</td><td>98.6</td></tr>
<tr><td colspan="5">Frequent coughing</td></tr>
<tr><td>Low emitter</td><td>0.057251</td><td>0.025709</td><td>0.008779</td><td>0.004524</td></tr>
<tr><td>Typical emitter</td><td>57.251</td><td>25.709</td><td>8.779</td><td>4.524</td></tr>
<tr><td>High emitter</td><td>7442598</td><td>3342148</td><td>1141326</td><td>588093</td></tr>
</table>
</td></tr>
<tr><td rowspan="2">SARS-CoV-2</td><td rowspan="2">Faulkner et al., 2021(45)</td><td rowspan="2">The paper outlines a comprehensive methodology for evaluating the effectiveness of various HVAC operation</td><td colspan="2">Numbers of air changes per hour (ACH) for optimal ventilation</td></tr>
<tr><td>Interventions:
Supplying 100% Outdoor Air: This</td><td>Supplying 100% Outdoor Air showed the lowest normalized virus concentration across all strategies, indicating its effectiveness in reducing indoor virus concentration compared to the baseline MERV-10 filtration.</td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year / Country</th><th>Objective / Methods</th><th>Intervention / Outcome / Scenarios</th><th>Summary of Findings</th></tr>
<tr><td rowspan="3"></td><td rowspan="3">United States</td><td rowspan="3">strategies in improving indoor air quality and reducing the risk of virus transmission, specifically in the context of the COVID-19 pandemic. The study focuses on a medium office building situated in a cold and dry climate, employing computational modules to assess the trade-offs between exposure risk, HVAC capacity, and energy use.

Methodology: The study examines the generation and decay rates of viruses in indoor environments, considering factors like occupancy and activities. It evaluates the efficiency of various HVAC filtration strategies, including MERV-10, MERV- 13, and HEPA filters, in removing virus particles from the air. The impact of using 100% outdoor air for ventilation on indoor air quality and energy consumption is also analyzed. These models are integrated into a whole building model to simulate real-world scenarios and assess the outcomes of different strategies. Finally, the study conducts a comparative analysis of the effectiveness and energy consumption of</td><td>strategy involves using only outdoor air for ventilation, without recirculating indoor air.

Comparators: The baseline for comparison is the building average virus concentration for the MERV-10 case, denoted as (c_0).

Key outcomes: Virus Concentration</td><td>
<table>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Result</th><th rowspan="2">Strategy</th><th colspan="3">Virus generation rates quanta/h</th></tr>
<tr><th>2</th><th>25</th><th>50</th></tr>
<tr><td rowspan="12">Hot summer day</td><td rowspan="4">Sample Day Virus Concentration reduction</td><td>MERV-10</td><td>-</td><td>-</td><td>Baseline</td></tr>
<tr><td>100% Outdoor Air</td><td>-</td><td>-</td><td>Up to 22</td></tr>
<tr><td>MERV-13</td><td>-</td><td>-</td><td>Up to 17%</td></tr>
<tr><td>HEPA</td><td>-</td><td>-</td><td>Up to 14%</td></tr>
<tr><td rowspan="4"><i>R</i>0</td><td>MERV-10</td><td rowspan="4">between 0.03 and 0.04</td><td rowspan="4">slightly under 50%</td><td rowspan="4">0.75</td></tr>
<tr><td>100% Outdoor Air</td></tr>
<tr><td>MERV- 13</td></tr>
<tr><td>HEPA</td></tr>
<tr><td rowspan="4"><i>R</i>0 reduction</td><td>MERV- 10</td><td>-</td><td>Baseline</td><td>Baseline</td></tr>
<tr><td>100% Outdoor Air</td><td>-</td><td>0.10</td><td>0.20</td></tr>
<tr><td>MERV- 13</td><td>-</td><td>0.08</td><td>0.15</td></tr>
<tr><td>HEPA</td><td>-</td><td>0.06</td><td>0.13</td></tr>
<tr><td rowspan="8">Mild spring day</td><td rowspan="4"><i>R</i>0</td><td>MERV- 10</td><td rowspan="4">0.04</td><td rowspan="3">0.44</td><td rowspan="3">0.85</td></tr>
<tr><td>100% Outdoor Air</td></tr>
<tr><td>MERV- 13</td></tr>
<tr><td>HEPA</td><td>-</td><td>-</td></tr>
<tr><td rowspan="4"><i>R</i>0 reduction</td><td>MERV-10</td><td>-</td><td rowspan="3">0.07</td><td rowspan="3">0.15</td></tr>
<tr><td>100% Outdoor Air</td><td>-</td></tr>
<tr><td>MERV- 13</td><td>-</td></tr>
<tr><td>HEPA</td><td>-</td><td>Baseline</td><td>Baseline</td></tr>
</table>
Supplying 100% outdoor air showed the most significant reduction in virus concentration compared to filtration methods.
</td></tr>
<tr><th colspan="2">Filters and filter ratings to use in a mechanical ventilation system</th></tr>
<tr><td>Interventions:
MERV- 10
Filtration: A filtration strategy using filters with a MERV-10.
MERV- 13
Filtration: A higher efficiency filtration strategy using MERV-13 filters.

HEPA
Filtration: The use of High-Efficiency Particulate Air</td><td>
<table>
<tr><th>Scenario</th><th>Strategy</th><th>Reduction in building-average virus concentration</th></tr>
<tr><td rowspan="4">Annual Virus Concentration</td><td>MERV- 10</td><td>Baseline</td></tr>
<tr><td>100% Outdoor Air</td><td>About 11%</td></tr>
<tr><td>MERV- 13</td><td>About 10%</td></tr>
<tr><td>HEPA</td><td>About 5%</td></tr>
</table>
MERV-13 and HEPA Filtration strategies resulted in reduced virus concentrations compared to the MERV- 10 baseline. The HEPA filtration, despite its high efficiency, was limited by the supply fan's capacity, which was not sized for the increased pressure drop, leading to reduced airflow and thus a slightly less effective reduction in virus concentration.
Implementation of MERV-10 filtration resulted in a reduction of virus concentration compared to baseline conditions.
</td></tr>
</table>

<table>
<tr><th>RIDs</th><th>Reference Year / Country</th><th>Objective / Methods</th><th>Intervention / Outcome / Scenarios</th><th>Summary of Findings</th></tr>
<tr>
<td></td>
<td></td>
<td>the different HVAC operation strategies.</td>
<td>(HEPA) filters, which are even more efficient than MERV-13 filters.

The baseline for comparison is the building average virus concentration for the MERV-10 case, denoted as (c_0).

Key outcomes: Virus Concentration</td>
<td>

Adoption of MERV-13 filtration led to a further decrease in virus concentration compared to MERV-10 filtration.
Application of HEPA filtration resulted in a substantial reduction in virus concentration compared to both MERV-10 and MERV-13 filtration.

<table>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Result</th><th rowspan="2">Strategy</th><th colspan="3">Virus generation rates quanta/h</th></tr>
<tr><th>2</th><th>25</th><th>50</th></tr>
<tr><td rowspan="12">Hot summer day</td><td rowspan="4">Sample Day Virus Concentration reduction</td><td>MERV-10</td><td>-</td><td>-</td><td>Baseline</td></tr>
<tr><td>100% Outdoor Air</td><td>-</td><td>-</td><td>Up to 22</td></tr>
<tr><td>MERV-13</td><td>-</td><td>-</td><td>Up to 17%</td></tr>
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<tr><td rowspan="4"><i>R</i>0</td><td>MERV-10</td><td rowspan="4">between 0.03 and 0.04</td><td rowspan="4">slightly under 50%</td><td rowspan="4">0.75</td></tr>
<tr><td>100% Outdoor Air</td></tr>
<tr><td>MERV-13</td></tr>
<tr><td>HEPA</td></tr>
<tr><td rowspan="4"><i>R</i>0 reduction</td><td>MERV-10</td><td>-</td><td>Baseline</td><td>Baseline</td></tr>
<tr><td>100% Outdoor Air</td><td>-</td><td>0.10</td><td>0.20</td></tr>
<tr><td>MERV-13</td><td>-</td><td>0.08</td><td>0.15</td></tr>
<tr><td>HEPA</td><td>-</td><td>0.06</td><td>0.13</td></tr>
<tr><td rowspan="8">Mild spring day</td><td rowspan="4"><i>R</i>0</td><td>MERV-10</td><td rowspan="4">0.04</td><td rowspan="3">0.44</td><td rowspan="3">0.85</td></tr>
<tr><td>100% Outdoor Air</td></tr>
<tr><td>MERV-13</td></tr>
<tr><td>HEPA</td><td>-</td><td>-</td></tr>
<tr><td rowspan="4"><i>R</i>0 reduction</td><td>MERV-10</td><td>-</td><td rowspan="3">0.07</td><td rowspan="3">0.15</td></tr>
<tr><td>100% Outdoor Air</td><td>-</td></tr>
<tr><td>MERV-13</td><td>-</td></tr>
<tr><td>HEPA</td><td>-</td><td>Baseline</td><td>Baseline</td></tr>
</table>
Seasonal variations affected the effectiveness of these strategies, with the MERV-10 and MERV-13 cases showing the lowest average virus concentrations during mild weather months (April, October, November) and the highest during the hot summer months due to minimum outdoor air supply.
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<tr>
<td rowspan="2">SARS-CoV-2</td>
<td rowspan="2">Yuce et al., 2023 (65)

Turkey</td>
<td rowspan="2">The aim of the study was to evaluate the influence of different factors on pathogen concentration in a room equipped with DV, using Computational Fluid Dynamics (CFD) and the Taguchi method to overcome</td>
<td colspan="2">HVAC systems (e.g. displacement, mixing systems)</td>
</tr>
<tr>
<td>Intervention: Different levels of inlet velocity.

Key outcomes: Pathogen concentration</td>
<td>

Increasing inlet velocity significantly reduced pathogen concentration in indoor environments, demonstrating its role as the most influential parameter among those investigated. This effect was consistent across different room designs and parameter ranges, indicating a non-linear relationship between velocity and concentration but underscoring the paramount importance of inlet velocity in minimizing airborne pathogen transmission.
Direct airflow directed toward the contaminant source, specifically aligning the inlet and outlet with the manikin and positioning the manikin facing the outlet, significantly reduced pathogen

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</table>

RIDs	Reference Year / Country	Objective / Methods	Intervention / Outcome / Scenarios	Summary of Findings
		the challenges of analyzing multiple physical factors simultaneously. **Methodology:** The study used Computational Fluid Dynamics (CFD) and the Taguchi statistical method to optimize ventilation parameters for reducing airborne pathogen concentration in an office setting. CFD simulations were used to model airflow and pathogen distribution, while the Taguchi method was applied to evaluate the impact of various ventilation parameters on pathogen concentration. The study focused on key ventilation parameters such as inlet velocity, inlet temperature, positions of inlet and outlet, and room dimensions. The optimal conditions for each parameter were identified using the Taguchi method and their effectiveness in minimizing pathogen concentration was numerically verified. The findings were further validated by applying the Taguchi method to the Wells-Riley method, an infection risk prediction model.		concentration, even in small room volumes. Room dimensions were found to be the least influential factor in reducing pathogen concentration. • Inlet velocity was identified as the most influential parameter on pathogen transmission, with higher velocity values correlating to lower CO2 mass fraction values. However, the relationship between velocity and concentration was not linear, and the impact rate of inlet velocity on concentration remained consistent across different room designs and parameter ranges. • The application of the Taguchi method to the Wells-Riley equation demonstrated that inlet velocity had a significantly larger effect on infection risk compared to room volume, contributing to approximately 97.16% of the infection risk.
			Environmental conditions to target for optimal ventilation	
			Intervention: inlet temperature **Key outcomes:** Pathogen concentration	**Inlet Temperature:** The study observed that inlet temperature had distinct effects on CO_2 mass fraction at different levels, with a more pronounced impact in smaller volumes. This suggests that adjusting inlet temperature can be an effective strategy for controlling pathogen transmission, especially in smaller indoor environments. However, the specific pattern of concentration relative to temperature was not linear, indicating the need for optimization studies to establish the most effective temperature settings.
			Building/room designs and ventilation types in building designs	
			Intervention: Various configurations of inlet and outlet positions were examined, including their alignment with the manikin and the direction of airflow towards the contaminant source. **Key outcomes:** Pathogen concentration	Inlet and Outlet Positions: While not as influential as inlet velocity, the positions of the inlet and outlet still played a role in pathogen concentration. • The study's configuration, aligned with natural airflow patterns due to buoyancy forces, suggests that thoughtful placement of ventilation components can contribute to reducing pathogen transmission, although it is secondary to the impact of inlet velocity. • Directing airflow towards the contaminant source, particularly by aligning the inlet and outlet with the manikin, emerged as the most effective strategy for reducing pathogen concentration. This approach yielded significantly lower concentration values, especially notable in smaller room volumes, thereby highlighting the effectiveness of strategic airflow direction in combating pathogen spread. • Room dimensions, including length, width, and height, were found to have minimal influence on pathogen concentration, suggesting that the impact of room volume on airborne pathogen transmission is negligible.
			Building/room designs and ventilation types in building designs	

RIDs	Reference Year / Country	Objective / Methods	Intervention / Outcome / Scenarios	Summary of Findings
SARS-CoV-2	Martinez et al., 2022 (74) Spain	The study develops ArchABM, a simulator for human-building interactions, to calculate indoor air quality (IAQ) and physiological responses. It evaluates the impact of building and policy measures on IAQ and occupants' responses. The goal is to help professionals estimate room sizes, set ventilation parameters, and test policies considering IAQ. **Methodology:** The methodology employed in the study revolves around the use of ArchABM, an agent-based modelling framework designed to simulate human-building interactions and their impact on indoor air quality (IAQ) and virus concentrations, specifically focusing on airborne viruses like SARS-CoV-2. The simulator integrates various parameters and models to estimate the effects of different building and policy measures on IAQ. Key components of the methodology include simulation of indoor environments, agent-Based Modelling, trial simulations and evaluation of interventions.	**Interventions:** 1. Larger building: each room's area (and thus each room's volume) is increased by 20%. 2. Separate workspaces: the open office is divided into three identical offices, each one with 110 m2, 16 people (48/3), and a capacity of 20 (60/3). 3. Better natural ventilation: windows are opened everywhere except in restrooms for better outdoor air supply. 4. Better mechanical ventilation: the flow rate QAC of the AC system is incremented, assuming a 20% filter efficiency, a 10% of removal in ducts and no additional removal measures. **Key Outcomes:** maximum virus quanta level (concentration in ppm) reached during the day per place are calculated.	**Results for places:** • The design of a larger building in terms of room area reduces the maximum quanta level in every room by up to 18%. • Separate workspaces have a significant impact exclusively in the open office, which is divided into three distinct spaces according to this strategy. This building configuration specifically raises the maximum quanta level in the open office by up to 57%. This increase in the mean quanta level is because in this experiment, one of the three spaces is more likely to be highly contaminated, which raises the mean value. • Better natural ventilation system design improves indoor air quality in terms of quanta, especially in meeting rooms. • Installing better mechanical ventilation systems reduces quanta concentration levels in all rooms, with a greater impact in chief offices and meeting rooms. **Results for whole building**: • Concerning the building-related measures, increasing each room's area by 20% reduces, on average, the maximum CO2 level by 8% and the maximum quanta level by 17%. However, the cost of these solutions must be carefully considered, and in some cases, they are not a financially viable option. • Creating separate workspaces does not affect either the CO2 or quanta levels at the building level. However, the results from the perspective of the place claim that it affects the modified spaces. • Increasing the natural ventilation, the outdoor air exchange rate, reduces, on average, the maximum CO2 level by 29% and the maximum quanta level by 54%. This measure improves the IAQ of the building and is a crucial parameter to control the indoor air quality, as expected. Increasing the mechanical ventilation rate improves the quanta level by 33% but does not modify the CO_2 concentration level, as there is no outdoor air supply, the air is merely recirculated. Although virus quanta can be removed from recirculated air, the CO_2 level remains unchanged. Combining better natural ventilation and limiting the duration of meetings and lunch events has a significant effect on both CO_2 and quanta levels. This case combines the most promising measures from the above experiments and reduces, on average, the maximum CO_2 level by 31% and the maximum quanta level by 65%.

LES 15.2: Effectiveness of VAFD measures for reducing transmission of RIDs in non-health care community-based settings.

RIDs	Reference Year / Country	Objective / Methods	Intervention / Outcome / Scenarios	Summary of Findings
Evidence gaps				
No data yet	Combinations of ventilation and filtration strategies / Portable air cleaners			

Abbreviations: CFD = computational fluid dynamics; CO_2 = carbon dioxide

Table 5: Summary of studies reporting on negative outcomes of portable air purifiers for reducing COVID-19 infections (n=1)

Last updated 12th March 2023

Author Year Country	Setting and time covered	Study characteristics	Summary of key findings in relation to the outcome(s)	RoB
Granzin (90) November 5, 2022 Germany	Two schools in Bad Homburg vor der Hohe, Germany November 2020 – June 2021 (monthly measurements) Surveys completed in July and December 2021	**Design**: epidemiological study measuring efficiency of mobile air purifiers (no transmission outcome); followed by two (summer and winter) anonymous cross-sectional surveys on the acceptance of air purifiers in classrooms **Intervention**: four different models of air purifiers with HEPA filters (all rated >99.97% efficiency); all with mesh + activated charcoal + electret HEPA (regular household appliance), except the Trotec TAC V+ with F9 + H14 HEPA (commercial device) **Sample**: two schools ranging in classroom size of 8-28 students plus one teacher; survey involved staff and students (grades 5-12, ages 10-19) at one school **Key Outcomes**: acceptance (e.g., noise level, communication, concentration) **Agents assessed**: SARS-CoV-2	<u>Survey #1</u> (summer, in months prior sound pressure of devices was ~55dB; 1070 students, 22 teachers responded) 48% of students and 54% of teachers found noise levels “rather disturbing” or “very disturbing”; 22% of students and 27% of teachers found noise levels “not disturbing” or “marginally disturbing.” Majority found communication in class “difficult but possible” (42% students, 63% teachers) or “strongly impaired” (10% students, 5% teachers) Majority found ability to concentrate was “good” or “very good” (55% students, 71% teachers); minority found ability to concentrate was “rather bad” or “very bad” (16% students, 10% teachers) <u>Survey #2</u> (winter, in months prior sound pressure of devices was ~47 dB; 1060 students, 74 teachers responded) 24% of students and 20% of teachers found noise levels “rather disturbing” or “very disturbing”; 49% of students and 59% of teachers found noise levels “not disturbing” or “marginally disturbing.” Majority found communication in class “possible without problems” (26% students, 25% teachers) or “usually possible” (44% students, 50% teachers) Fraction of students supporting use of air purifiers increased by 17% from summer to winter survey; difference for teachers was marginal. Majority found ability to concentrate was “good” or “very good” (62% students, 83% teachers); minority found ability to concentrate was “rather bad” or “very bad” (11% students, 9% teachers)	Critical

<u>**Abbreviations**</u>: HEPA = high-efficiency particulate absorbing

Acknowledgements

To help Canadian decision-makers as they respond to unprecedented challenges related to the COVID-19 pandemic, COVID-END in Canada is preparing evidence syntheses like this one. This living evidence synthesis was commissioned by the Office of the Chief Science Officer, Public Health Agency of Canada. The development and continued updating of this living evidence synthesis has been funded by the Canadian Institutes of Health Research (CIHR) and the Public Health Agency of Canada. The opinions, results, and conclusions are those of the team that prepared the evidence synthesis, and independent of the Government of Canada, CIHR, and the Public Health Agency of Canada. No endorsement by the Government of Canada, Public Health Agency of Canada or CIHR is intended or should be inferred.

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Appendices

Appendix 1: Detailed search strategy (PubMed) *Last updated March 28th 2024*

PubMed Search:	
#1	("environmental monitoring"[MeSH Terms] OR "sanitary engineering"[MeSH Terms] OR "environment, controlled"[MeSH Terms] OR "ventilation"[MeSH Terms] OR "Filtration"[MeSH Terms] OR "air pollution, indoor"[MeSH Terms] OR "air filters"[MeSH Terms] OR "air microbiology"[MeSH Terms] OR "air ventilation"[Title/Abstract] OR "filters"[Title/Abstract] OR "airframe"[Title/Abstract] OR "air purification"[Title/Abstract] OR "air sample*"[Title/Abstract] OR "indoor air"[Title/Abstract] OR "air clean*"[Title/Abstract] OR "air condition*"[Title/Abstract] OR "aircondition*"[Title/Abstract] OR "outdoor air"[Title/Abstract]) OR "clean air"[Title/Abstract] OR "air disinfection"[Title/Abstract] OR "air filt*"[Title/Abstract] OR "air exchange"[Title/Abstract] OR "air change"[Title/Abstract] OR "air flow"[Title/Abstract] OR "airflow"[Title/Abstract] OR "return air"[Title/Abstract] OR "building ventilation"[Title/Abstract] OR "ventilation system*"[Title/Abstract] OR "indoor ventilation"[Title/Abstract] OR "ventilation rate"[Title/Abstract] OR "ventilation improv*"[Title/Abstract] OR "natural ventilation"[Title/Abstract] OR "demand controlled ventilation"[Title/Abstract] OR "Filter Cassettes"[Title/Abstract] OR "BioSampler"[Title/Abstract] OR "Button Sampler"[Title/Abstract] OR "AerosolSense"[Title/Abstract] OR "hepa filt*"[Title/Abstract] OR "Ultraviolet germicidal irradiation"[Title/Abstract] OR "UVGI"[Title/Abstract] OR "HVAC"[Title/Abstract] OR "high efficiency particulate arrestance"[Title/Abstract] OR "supply diffusers"[Title/Abstract]
#2	("coronavirus infections"[MeSH Terms] OR "COVID-19"[MeSH Terms] OR "SARS-CoV-2"[MeSH Terms] OR "Severe Acute Respiratory Distress Syndrome"[Title/Abstract] OR "SARS"[Title/Abstract] OR "MERS"[Title/Abstract] OR "sars cov"[Title/Abstract] OR "COVID-19"[Title/Abstract] OR "coronavirus disease"[Title/Abstract] OR "novel coronavirus"[Title/Abstract] OR "novel 2019 coronavirus"[Title/Abstract] OR "nCoV"[Title/Abstract] OR "2019nCoV"[Title/Abstract] OR "19nCoV"[Title/Abstract] OR "h1n1"[Title/Abstract]
#3	("respiratory syncytial viruses"[MeSH Terms] OR "respiratory syncytial virus*"[Title/Abstract] OR "Chimpanzee Coryza"[Title/Abstract] OR "Orthopneumovirus"[Title/Abstract])
#4	"orthomyxoviridae infections"[MeSH Terms] OR "Orthomyxoviridae"[MeSH Terms] OR "orthomyxovir*"[Title/Abstract] OR "Influenza"[Title/Abstract] OR "myxoviruses"[Title/Abstract] OR "influenza, human"[MeSH Terms] OR "influenza in birds"[MeSH Terms] OR "Avian Flu"[Title/Abstract] OR "avian influenza"[Title/Abstract] OR "swine flu"[Title/Abstract]
#5	("measles"[MeSH Terms] OR "measles"[Title/Abstract] OR "rubeola"[Title/Abstract])
#6	("clinical trial"[Publication Type] OR "trial"[Title] OR "randomized controlled trial"[Publication Type] OR "stud*"[Title] OR "cohort"[Title/Abstract] OR "case-control"[Title/Abstract] OR "casecontrol"[Title/Abstract] OR "cross-sectional"[Title/Abstract] OR "crosssectional"[Title/Abstract] OR "comparative study"[Publication Type] OR "Controlled Clinical Trial"[Publication Type] OR "quasiexperimental"[Title/Abstract] OR "quasi-experimental"[Title] OR "comparative study"[Title/Abstract] OR "modelling"[Title/Abstract] OR "simulation"[Title/Abstract] OR "observational study"[Publication Type] OR "observational"[Title/Abstract] OR "randomized"[Title/Abstract] OR "controlled"[Title/Abstract])
#7	#2 OR #3 OR #4 OR #5
#8	#7 AND #1 AND #6 AND 20200101-20241231

Appendix 2: Detailed study eligibility criteria

Last updated March 28th 2024

Characteristic	**Inclusion Criteria**	**Exclusion Criteria**
Publication date	January 01, 2020	Prior to 2020
Language	English	Languages other than English
Study design	Epidemiological / Ecological: experimental studies at the population or group level with a comparator Primary / Experimental: quantitative with comparator Primary / Observational: cohort, case-control, cross-sectional Modelling Studies	Opinions pieces: commentaries or editorials published in peer-reviewed journals. Qualitative studies Reviews: narrative and literature reviews; check references of systematic/rapid reviews or meta-analysis with relevant to any of the public health measures Case reports and case series
Population	All ages	Involving animals
Setting	Indoor built environments such as: office buildings, public buildings (schools, day cares), residential buildings, retail buildings (malls, restaurants), athletic facilities (gyms), transport vehicles (aircraft) or hubs (airports)	Healthcare or clinical settings
Intervention	a. Ventilation systems in the built environment b. Filters or filtration features within mechanical ventilation systems c. ACH d. Portable air cleaners e. Ventilation layout configurations f. Report on other public health measures (e.g., cleaning and disinfecting, quarantine) in addition to VAFD, but data related VAFD presented separately.	Studies that report on combinations of PHSMs (e.g., through longitudinal, cross-national analyses) without reporting on VAFD individually. Open air / outdoor environments Studies that focus on air flow only (e.g. opening windows or doors)
Comparison	Different rates and mechanisms (i.e., mechanical, natural, or filtration) of air dilution (including flow rates, air flow patterns, ratio of outdoor air to re-used air) Different filter ratings Different combinations of ventilation and filtration strategies	No comparison of ventilation parameters
Outcome	Quantitative data evaluating effectiveness in reducing transmission of RIDs (i.e., attack rates, reproduction number, etc.) Effectiveness at reducing the concentration of infectious particles in the air.	Qualitative data Noninterest outcomes

Abbreviations: TBD=to be determined

Appendix 3: Studies excluded at the last stages of reviewing

Last updated 28th March 2024

Study	Exclusion reason	Version
Abbas, 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Abbas et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Abuhegazy et al., 2020	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Acharya et al., 2023	Wrong Setting	Excluded in LES 15.2
Adzic et al., 2022	Wrong Intervention	Excluded in LES 15.2
Afrasiabian et al., 2022	Wrong Outcome	Excluded in LES 15.2
Aganovic et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Agarwal et al, 2021	Wrong Study Design	Excluded in LES 15.2
Aghdam et al., 2021	Wrong Outcome	Excluded in LES 15.2
Aguilar et al., 2022	Wrong Outcome	Excluded in LES 15.1
Ahmadi et al., 2021	Wrong Study Design	Excluded in LES 15.2
Ahmadzadeh at el., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Ahmadzadeh & Shams., 2022	Wrong Outcome	Excluded in LES 15.1
Ahmed et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ajirun et al., 2021	Wrong Intervention	Excluded in LES 15.1
Akamatsu et al.,2023	Wrong Study Design	Excluded in LES 15.1
Al-Rikabi et al., 2024	Wrong Study Design	Excluded in LES 15.2
Alaidroos et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Alencar et al., 2022	Wrong Intervention	Excluded in LES 15.2
Alhassan et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Aliyu et al.,2021	Wrong Intervention	Excluded in LES 15.1
Alser et al., 2022	Wrong Intervention	Excluded in LES 15.2
Alsved et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Álvaro-Meca et al., 2022	Wrong Outcome	Excluded in LES 15.2
Ameen et al., 2021	Wrong Intervention	Excluded in LES 15.2
Annadurai et al., 2024	Wrong Study Design	Excluded in LES 15.2
Arias & De las Heras, 2021	Wrong Setting	Excluded in LES 15.2
Arjmandi et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Armand et al., 2022	Wrong Outcome	Excluded in LES 15.1
Arpino et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Arslan, 2022	Wrong Setting	Excluded in LES 15.2
Ascione et al.,2021	Wrong Outcome	Excluded in LES 15.1
Azevedo et al., 2022	Wrong Intervention	Excluded in LES 15.1
Azimi et al., 2020	Wrong Intervention	Excluded in LES 15.1
Babuna et al., 2021	Wrong Intervention	Excluded in LES 15.2
Baghani et al., 2022	Wrong Intervention	Excluded in LES 15.2
Bahramian et al., 2022	Wrong Outcome	Excluded in LES 15.2
Bai et al., 2023	Wrong Intervention	Excluded in LES 15.1
Baig et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Balagna et al., 2021	Wrong Setting	Excluded in LES 15.2
Bale et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Bandara et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Banholzer et al., 2023	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Banholzer et al., 2024	Wrong Intervention	Excluded in LES 15.2
Barbosa et al., 2021	Portable purifier modelling study with infection outcome	Excluded in LES 15.1
Barbosa et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Barnewall & Bischoff, 2021	Wrong Setting	Excluded in LES 15.2
Baselga, et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Bazant et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Becchio et al., 2023	Wrong Outcome	Excluded in LES 15.2
Beggs & Avital, 2020	Wrong Intervention	Excluded in LES 15.1
Belser et al., 2022	Wrong Setting	Excluded in LES 15.2
Bennett et al., 2022	Wrong Intervention	Excluded in LES 15.1
Bergman et al., 2020	Wrong Population / Wrong Microorganism	Excluded in LES 15.1

Bergman et al., 2021	Wrong Publication Type	Excluded in LES 15.2
Berry et al., 2022	Wrong Study Design	Excluded in LES 15.2
Bertone et al., 2022	Wrong Intervention	Excluded in LES 15.2
Beswick et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Bilal et al., 2021	Wrong Language	Excluded in LES 15.2
Birnir et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Biswas et al.,2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Blocken et al., 2021	Wrong Outcome	Excluded in LES 15.1
Boufekane et al; 2021	Wrong Intervention	Excluded in LES 15.2
Brainard et al., 2023	Wrong Study Design	Excluded in LES 15.2
Brass et al., 2022	Wrong Outcome	Excluded in LES 15.2
Brlek et al.,2020	Wrong Intervention	Excluded in LES 15.1
Brouwers et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Bueno de Mesquita, et al., 2020	Wrong Intervention	Excluded in LES 15.2
Bu et al., 2021	Wrong Study Design	Excluded in LES 15.2
Buchan et al., 2021	Wrong Intervention	Excluded in LES 15.2
Buchwald et al., 2023	Wrong Outcome	Excluded in LES 15.2
Bui et al., 2022	Wrong Setting	Excluded in LES 15.2
Bukhari et al., 2020	Wrong Intervention	Excluded in LES 15.2
Buonanno et al., 2020	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Buonanno et al.,2020	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Buonanno et al., 2021	Wrong Outcome	Excluded in LES 15.2
Buonomano et al., 2023	Wrong Outcome	Excluded in LES 15.2
Burgmann et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Burridge et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Cadnum et al., 2022	Wrong Setting	Excluded in LES 15.1
Cadnum et al.,2022	Wrong Intervention	Excluded in LES 15.1
Cao et al., 2023	Wrong Intervention	Excluded in LES 15.2
Carleton et al., 2021	Wrong Intervention	Excluded in LES 15.2
Carlotti et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Carrazana et al., 2023	Wrong Study Design	Excluded in LES 15.2
Castellani et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Cerrato & Fumo, 2024	Wrong Publication Type	Excluded in LES 15.2
Cha et al., 2023	Wrong Setting	Excluded in LES 15.2
Chang et al., 2021	Wrong Outcome	Excluded in LES 15.2
Chang et al., 2023	Wrong Study Design	Excluded in LES 15.2
Chang et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Chaudhary et al., 2022	Wrong Outcome	Excluded in LES 15.2
Chaussade et al., 2022	Wrong Setting	Excluded in LES 15.1
Chien et al., 2022	Wrong Outcome	Excluded in LES 15.2
Chien et al., 2022	Wrong Outcome	Excluded in LES 15.2
Che et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Chen et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Chen et al., 2021	Wrong Intervention	Excluded in LES 15.2
Chen et al., 2021	Wrong Intervention	Excluded in LES 15.2
Chen et al., 2024	Wrong Study Design	Excluded in LES 15.2
Cheng et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Cheng et al.,2022	Wrong Intervention	Excluded in LES 15.1
Cheung et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Cho et al., 2022	Wrong Setting	Excluded in LES 15.1
Cho et al., 2022	Wrong Intervention	Excluded in LES 15.2
Choe et al., 2022	Wrong Intervention	Excluded in LES 15.1
Choi et al., 2021	Wrong Study Design	Excluded in LES 15.2
Choi et al., 2023	Wrong Setting	Excluded in LES 15.2
Cilhoroz & DeRuisseau, 2021	Wrong Study Design	Excluded in LES 15.2
Clouston et al., 2021	Wrong Outcome	Excluded in LES 15.2
Coldrick et al., 2022	Wrong Study Design	Excluded in LES 15.2
Collins et al., 2021	Wrong Study Design	Excluded in LES 15.1
Collin et al., 2023	Wrong Intervention	Excluded in LES 15.2

Corrêa et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Correia et al., 2020	Wrong Study Design	Excluded in LES 15.2
Cortes & Zuñiga, 2020	Wrong Study Design	Excluded in LES 15.2
Costa et al., 2023	Wrong Outcome	Excluded in LES 15.2
Coyle et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Coyle et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Cui et al., 2021	Wrong Intervention	Excluded in LES 15.1
Cummings et al., 2024	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Curtius et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Cuthbert et al., 2021	Wrong Intervention	Excluded in LES 15.2
D'Alicandro et al., 2024	Wrong Outcome	Excluded in LES 15.2
Dai et al., 2020	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Dai et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Dai et al., 2023	Wrong Intervention	Excluded in LES 15.1
Dai & Zhao., 2022	Portable purifier modelling study with infection outcome	Excluded in LES 15.1
Dai et al., 2023	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Dbouk et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Dbouk et al., 2021	Wrong Intervention	Excluded in LES 15.2
Dbouk et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Dbouk & Drikakis. 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
De-Almeida et al., 2020	Wrong Setting	Excluded in LES 15.2
De-Almeida et al., 2022	Wrong Study Design	Excluded in LES 15.2
de Crane D'Heysselaer et al., 2023	Wrong Study Design	Excluded in LES 15.2
Deng et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Deng & Gong, 2021	Wrong Outcome	Excluded in LES 15.2
Derk et al., 2023	Wrong Outcome	Excluded in LES 15.1
Desai et al; 2021	Wrong Outcome	Excluded in LES 15.2
Di Gilio et al., 2021	Wrong Outcome	Excluded in LES 15.2
D'Orazio et al., 2021	Wrong Intervention	Excluded in LES 15.2
Domínguez-Amarillo et al., 2020	Wrong Intervention	Excluded in LES 15.1
Donzelli et al., 2022	Wrong Intervention	Excluded in LES 15.2
Donskey, 2023	Wrong Study Design	Excluded in LES 15.2
Doughty et al., 2020	Wrong Outcome	Excluded in LES 15.2
Downing et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Du et al., 2022	Wrong Intervention	Excluded in LES 15.2
Du & Chen., 2024	Wrong Outcome	Excluded in LES 15.2
DuBois et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Dubuis et al., 2021	Wrong Setting	Excluded in LES 15.2
Duchaine & Roy, 2022	Wrong Publication Type	Excluded in LES 15.2
Duill et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Duval et al., 2022	Wrong Study Design	Excluded in LES 15.2
Eadie et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Ebadi et al., 2022	Wrong Setting	Excluded in LES 15.2
Ebrahimifakhar et al., 2023	Wrong Study Design	Excluded in LES 15.2
Edwards et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Elsaid et al., 2021	Wrong Study Design	Excluded in LES 15.1
Elsaid et al., 2021	Wrong Study Design	Excluded in LES 15.2
Elsarraj et al., 2024	Wrong Intervention	Excluded in LES 15.2
Essa et al., 2023	Wrong Setting	Excluded in LES 15.2
Fan et al., 2022	Wrong Study Design	Excluded in LES 15.2
Faulkner et al., 2023	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Feng et al., 2021	Wrong Setting	Excluded in LES 15.2
Fernandez de Mera et al., 2022	Wrong Intervention	Excluded in LES 15.1
Ferrari et al., 2022	Wrong Study Design	Excluded in LES 15.2
Fierce et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Fierce et al., 2021	Wrong Intervention	Excluded in LES 15.2
Firatoglu., 2023	Wrong Outcome	Excluded in LES 15.2
Foster et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Foster et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1

Franceschini & Neves, 2022	Wrong Study Design	Excluded in LES 15.2
Fredrich et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Gaillard et al., 2023	Wrong Intervention	Excluded in LES 15.1
Garzona-Navas et al., 2021	Wrong Setting	Excluded in LES 15.1
Geng et al., 2023	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Ghaddar & Ghali et al., 2022	Wrong Study Design	Excluded in LES 15.2
Giampieri et al., 2022	Wrong Study Design	Excluded in LES 15.1
Ginsberg., 2023	Wrong Outcome	Excluded in LES 15.2
González-Sancha et al., 2022	Wrong Outcome	Excluded in LES 15.2
Greentree et al., 2023	Wrong Outcome	Excluded in LES 15.2
Grygierek et al.,2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Günther et al., 2020	Wrong Intervention	Excluded in LES 15.1
Guan et al., 2022	Wrong Intervention	Excluded in LES 15.2
Guo et al., 2022	Wrong Intervention	Excluded in LES 15.2
Guo et al., 2022	Wrong Outcome	Excluded in LES 15.2
Guo et al., 2021	Wrong Study Design	Excluded in LES 15.2
Guo et al., 2021	Wrong Study Design	Excluded in LES 15.2
Guo et al., 2023	Wrong Outcome	Excluded in LES 15.2
Habibi et al., 2024	Wrong Outcome	Excluded in LES 15.2
Haj Bloukh et al., 2020	Wrong Intervention	Excluded in LES 15.1
Hammond et al., 2021	Wrong Study Design	Excluded in LES 15.1
Han., et al 2020	Wrong Outcome	Excluded in LES 15.2
Harrichandra et al.,2020	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Hassan et al., 2021	Wrong Intervention	Excluded in LES 15.2
Hayashi et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
He et al., 2021	Portable purifier modelling study with infection outcome	Excluded in LES 15.1
Hedworth et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Hegde., et al 2022	Wrong Intervention	Excluded in LES 15.2
Henderson et al., 2022	Wrong Intervention	Excluded in LES 15.2
Hessling et al., 2021	Wrong Study Design	Excluded in LES 15.2
Hildebrandt et al., 2022	Wrong Intervention	Excluded in LES 15.2
Hill et al., 2022	Wrong Intervention	Excluded in LES 15.2
Ho et al.,2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Ho et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Hobday & Collignon, 2022	Wrong Study Design	Excluded in LES 15.2
Horstman et al., 2021	Wrong Intervention	Excluded in LES 15.1
Hossain, 2022	Wrong Intervention	Excluded in LES 15.2
Hou et al.,2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Hu et al., 2022	Wrong Outcome	Excluded in LES 15.2
Huang et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Huang et al.,2022	Wrong Study Design	Excluded in LES 15.1
Huang et al., 2023	Wrong Outcome	Excluded in LES 15.2
Huessler et al.,2022	Wrong Outcome	Excluded in LES 15.1
Hui & Zhang, 2024	Wrong Outcome	Excluded in LES 15.2
Hurraß et al., 2022	Wrong Outcome	Excluded in LES 15.2
Hwang et al., 2022	Wrong Intervention	Excluded in LES 15.1
Iqbal et al., 2021	Wrong Intervention	Excluded in LES 15.2
Islam et al., 2020	Wrong Outcome	Excluded in LES 15.2
Issakhov et al., 2022	Wrong Intervention	Excluded in LES 15.2
Issman et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Izadyar & Miller., 2022	Wrong Study Design	Excluded in LES 15.2
Jahanbin & Semprini, 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Jain et al., 2021	Wrong Setting	Excluded in LES 15.1
Janoszek et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Jassim et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Jeong et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Jeong et al., 2022	Wrong Setting	Excluded in LES 15.2
Ji et al., 2022	Wrong Intervention	Excluded in LES 15.1
Jia et al., 2021	Wrong Study Design	Excluded in LES 15.2

Jia et al., 2022	Wrong Outcome	Excluded in LES 15.2
Jia et al., 2023	Wrong Intervention	Excluded in LES 15.2
Jiang et al., 2020	Wrong Intervention	Excluded in LES 15.2
Jiang et al., 2023	Wrong Intervention	Excluded in LES 15.1
Jiang et al., 2024	Wrong Outcome	Excluded in LES 15.2
Jones et al., 2023	Wrong Intervention	Excluded in LES 15.1
Jumlongkul, 2021	Wrong Setting	Excluded in LES 15.2
Jutkowitz et al., 2023	Wrong Intervention	Excluded in LES 15.2
Kachhadiya et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kaliszewski et al., 2020	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Kang et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Kapoor et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Kapoor et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Kapse et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Karaböce et al., 2022	Wrong Intervention	Excluded in LES 15.2
Karam et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Karam et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Karami et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kataki et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Katal et al., 2022	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Katramiz et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Katsumata et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kaushik & Dhau, 2022	Wrong Study Design	Excluded in LES 15.2
Kehler et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kennedy et al., 2021	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Khaliq et al., 2024	Wrong Outcome	Excluded in LES 15.2
Khan & Al-Saadi, 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Khan., 2021	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Khankari et al.,2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Kim et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Kim et al., 2021	Wrong Outcome	Excluded in LES 15.2
Kim et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kim et al., 2022	Wrong Setting	Excluded in LES 15.2
Kim et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Kitamura et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kwon et al.,2020	Wrong Study Design	Excluded in LES 15.1
Kohanski et al., 2020	Wrong Study Design	Excluded in LES 15.2
Kolarž et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Kompatscher et al., 2023	Wrong Study Design	Excluded in LES 15.2
Kong et al., 2023	Wrong Setting	Excluded in LES 15.1
Korhonen et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Krishnaprasad et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Krutikov et al., 2023	Wrong Setting	Excluded in LES 15.2
Kwak et al., 2023	Wrong Outcome	Excluded in LES 15.2
Kumar et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Kumar et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Kumar et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Kumar et al., 2023	Wrong Study Design	Excluded in LES 15.2
Kumara et al., 2023	Wrong Outcome	Excluded in LES 15.2
Kurnitski et al., 2023	Wrong Intervention	Excluded in LES 15.2
Kwok et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Lasser et al., 2022	Wrong Intervention	Excluded in LES 15.2
Lau et al., 2020	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Lee et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Lee et al., 2021	Wrong Outcome	Excluded in LES 15.2
Lee et al., 2021	Wrong Outcome	Excluded in LES 15.2
Lee et al., 2022	Wrong Setting	Excluded in LES 15.1
Lepore et al., 2021	Wrong Outcome	Excluded in LES 15.2
Leung & Sun, 2020	Wrong Setting	Excluded in LES 15.2

Lewis., 2023	Wrong Publication Type	Excluded in LES 15.2
Li et al., 2021	Wrong Intervention	Excluded in LES 15.1
Li et al., 2021	Wrong Intervention	Excluded in LES 15.1
Li et al., 2021	Wrong Intervention	Excluded in LES 15.2
Li et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Li et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Li et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Li et al.,2022	Wrong Setting	Excluded in LES 15.1
Li et al., 2022	Wrong Intervention	Excluded in LES 15.1
Li et al., 2022	Wrong Intervention	Excluded in LES 15.1
Li et al., 2022	Wrong Setting	Excluded in LES 15.1
Li et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Li et al., 2022	Wrong Outcome	Excluded in LES 15.2
Li et al.,2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Li et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Li et al., 2023	Wrong Setting	Excluded in LES 15.1
Li et al., 2023	Wrong Setting	Excluded in LES 15.2
Li et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Li., et al 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Li et al., 2023	Wrong Intervention	Excluded in LES 15.1
Li et al., 2023	Wrong Setting	Excluded in LES 15.2
Li et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Li et al., 2023	Wrong Outcome	Excluded in LES 15.2
Li et al., 2024	Wrong Setting	Excluded in LES 15.2
Li et al., 2024	Wrong Outcome	Excluded in LES 15.2
Liang & Yuan, 2022	Wrong Intervention	Excluded in LES 15.2
Li & Tang, 2022	Wrong Intervention	Excluded in LES 15.2
Li & Tang, 2021	Wrong Setting	Excluded in LES 15.1
Licina et al.,2021	Wrong Study Design	Excluded in LES 15.1
Llibre et al., 2021	Wrong Intervention	Excluded in LES 15.2
Lin et al., 2020	Wrong Intervention	Excluded in LES 15.2
Lin et al., 2020	Wrong Intervention	Excluded in LES 15.2
Lin et al., 2023	Wrong Study Design	Excluded in LES 15.2
Lindsley et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Lipinski et al., 2020	Wrong Study Design	Excluded in LES 15.2
Liu et al., 2021	Wrong Setting	Excluded in LES 15.2
Liu et al., 2021	Wrong Outcome	Excluded in LES 15.2
Liu et al., 2022	Wrong Outcome	Excluded in LES 15.1
Liu et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Liu et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Liu et al., 2022	Wrong Setting	Excluded in LES 15.2
Liu et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
López et al., 2023	Wrong Study Design	Excluded in LES 15.1
Lou et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Lovec et al., 2021	Wrong Outcome	Excluded in LES 15.2
Lu et al., 2022	Wrong Intervention	Excluded in LES 15.2
Lu et al., 2020	Wrong Study Design	Excluded in LES 15.1
Lub et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Luo., et al 2022	Wrong Setting	Excluded in LES 15.1
Luo et al., 2023	Wrong Intervention	Excluded in LES 15.2
Luo & Zhong, 2021	Wrong Study Design	Excluded in LES 15.2
Luo et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Luo et al., 2023	Wrong Publication Type	Excluded in LES 15.2
Ma et al., 2022	Wrong Setting	Excluded in LES 15.1
Malladi et al., 2021	Wrong Intervention	Excluded in LES 15.2
Mallakpour et al., 2022	Wrong Study Design	Excluded in LES 15.2
Mao et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Mariam et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Masoomi et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1

Masoomi et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Mateus et al., 2023	Wrong Study Design	Excluded in LES 15.2
Mboreha et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
McNeill et al., 2021	Wrong Outcome	Excluded in LES 15.2
Melikov et al., 202	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Memon et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Mendez et al., 2023	Wrong Intervention	Excluded in LES 15.2
Mesgarpour et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Mikszewski., et al 2021	Wrong Intervention	Excluded in LES 15.2
Miller et al., 2021	Wrong Setting	Excluded in LES 15.1
Miller et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Mirikar et al, 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Mirzaie et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Moeller et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Mohammad et al., 2020	Wrong Intervention	Excluded in LES 15.2
Mohammadi et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Mohamadi & Fazeli, 2022	Wrong Study Design	Excluded in LES 15.1
Monfared et al.,2022	Wrong Study Design	Excluded in LES 15.1
Monge-Barrio et al., 2022	Wrong Outcome	Excluded in LES 15.2
Moriyama et al., 2020	Wrong Study Design	Excluded in LES 15.2
Moses et al., 2020	Wrong Study Design	Excluded in LES 15.1
Motamedi et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Mouchtouri et al., 2020	Wrong Intervention	Excluded in LES 15.1
Mousavi et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Mukherjee et al., 2022	Wrong Intervention	Excluded in LES 15.1
Müller et al., 2021	Wrong Intervention	Excluded in LES 15.2
Muthusamy et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Myers et al., 2021	Wrong Intervention	Excluded in LES 15.1
Nair et al., 2022	Wrong Study Design	Excluded in LES 15.2
Narayan et al., 2022	Wrong Study Design	Excluded in LES 15.2
Narayanan & Yang. 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Navas et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Nazarenko, 2020	Wrong Publication Type	Excluded in LES 15.1
Nazari et al., 2021	Wrong Intervention	Excluded in LES 15.1
Nazari et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Nazari et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Negishi et al., 2022	Wrong Setting	Excluded in LES 15.2
Nguyen et al., 2022	Wrong Study Design	Excluded in LES 15.2
Nguyen-Van-Tam, 2020	Wrong Intervention	Excluded in LES 15.2
Nie et al., 2022	Wrong Intervention	Excluded in LES 15.2
Nikoopayan et al.,2023	Wrong Intervention	Excluded in LES 15.1
Nunayon et al., 2023	Wrong Study Design	Excluded in LES 15.2
Oberlin et al., 2022	Wrong Intervention	Excluded in LES 15.2
Obitková et al., 2024	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Oksanen et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ooi et al., 2021	Wrong Intervention	Excluded in LES 15.1
Osman et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ou et al., 2022	Wrong Outcome	Excluded in LES 15.2
Ouyang et al., 2022	Wrong Outcome	Excluded in LES 15.2
Ouyang et al., 2023	Wrong Study Design	Excluded in LES 15.2
Pal et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Pal et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Pampati et al., 2022	Wrong Outcome	Excluded in LES 15.2
Pampatti et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Pan et al., 2020	Wrong Intervention	Excluded in LES 15.2
Pan et al., 2021	Wrong Intervention	Excluded in LES 15.2
Pan et al., 2023	Wrong Intervention	Excluded in LES 15.2
Pana et al., 2021	Wrong Intervention	Excluded in LES 15.2
Parhizkar et al.,2022	Wrong Intervention	Excluded in LES 15.1

Parhizkar et al., 2022	Wrong Setting	Excluded in LES 15.1
Park & Song, 2023	Wrong Outcome	Excluded in LES 15.2
Park et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Park et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Park et al., 2022	Wrong Outcome	Excluded in LES 15.1
Park et al., 2023	Wrong Outcome	Excluded in LES 15.2
Pastor et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Pease et al., 2022	Portable purifier modelling study with infection outcome	Excluded in LES 15.1
Pecho et al., 2020	Wrong Study Design	Excluded in LES 15.2
Pei et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Pelletier et al.,2022	Wrong Intervention	Excluded in LES 15.1
Peng et al., 2020	Wrong Study Design	Excluded in LES 15.2
Peng et al., 2021	Wrong Outcome	Excluded in LES 15.2
Peng et al., 2022	Wrong Intervention	Excluded in LES 15.2
Peng et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Peng et al.,2023	Wrong Intervention	Excluded in LES 15.1
Penning & Weibel, 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Persis & Ben Amar., 2022	Wrong Intervention	Excluded in LES 15.2
Pirouz et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Piscitelli et al., 2022	Wrong Study Design	Excluded in LES 15.2
Pistochini et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Potter et al., 2022	Wrong Setting	Excluded in LES 15.1
Pourkarim et al., 2020	Wrong Publication Type	Excluded in LES 15.2
Qiao et al., 2021	Wrong Setting	Excluded in LES 15.2
Quin et al., 2023	Wrong Outcome	Excluded in LES 15.2
Quinones et al., 2022	Wrong Intervention	Excluded in LES 15.1
Quintero et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Rahvard et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ramajo et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Ramasamy, 2021	Wrong Study Design	Excluded in LES 15.2
Rao et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Rastani et al., 2023	Wrong Intervention	Excluded in LES 15.1
Ratliff et al., 2023	Wrong Setting	Excluded in LES 15.1
Rayegan et al., 2023	Wrong Study Design	Excluded in LES 15.1
Reimers et al, 2023	Wrong Setting	Excluded in LES 15.2
Ren et al., 2021	Wrong Intervention	Excluded in LES 15.2
Ren et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ren et al., 2024	Wrong Outcome	Excluded in LES 15.2
Rencken et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Rey-Hernández., et al 2023	Wrong Outcome	Excluded in LES 15.2
Rezaei et al., 2020	Wrong Setting	Excluded in LES 15.2
Rey-Hernández et al., 2020	Wrong Outcome	Excluded in LES 15.2
Ribeiro et al., 2024	Wrong Outcome	Excluded in LES 15.2
Riley et al., 2021	Wrong Intervention	Excluded in LES 15.2
Risbeck et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Rivas et al., 2022	Wrong Outcome	Excluded in LES 15.1
Rodríguez et al., 2022	Wrong Intervention	Excluded in LES 15.2
Rodríguez-Vidal et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Romano Spica et al., 2020	Wrong Study Design	Excluded in LES 15.1
Rowe., et al 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Rugani et al.,2021	Wrong Intervention	Excluded in LES 15.1
Rule et al., 2020	Wrong Study Design	Excluded in LES 15.1
Ruciński et al., 2021	Wrong Setting	Excluded in LES 15.2
Ryan, 2023	Wrong Intervention	Excluded in LES 15.2
Saccani et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Saeed et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Sajadi et al., 2020	Wrong Intervention	Excluded in LES 15.2
Sami et al., 2022	Wrong Intervention	Excluded in LES 15.1
Sankaran et al., 2023	Wrong Intervention	Excluded in LES 15.1

Sarhan et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Schroeder et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Seo et al., 2021	Wrong Intervention	Excluded in LES 15.2
Shao et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Saikaew & Intasanta, 2021	Wrong Intervention	Excluded in LES 15.2
Saw et al., 2022	Wrong Setting	Excluded in LES 15.1
Schmeling et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Sellera et al., 2021	Wrong Study Design	Excluded in LES 15.2
Sellaoui et al., 2021	Wrong Study Design	Excluded in LES 15.2
Shah et al., 2021	Wrong Setting	Excluded in LES 15.2
Shamim et al., 2022	Wrong Study Design	Excluded in LES 15.2
Shang et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Shang et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Shao et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Shen et al., 2020	Wrong Intervention	Excluded in LES 15.1
Shen et al., 2020	Wrong Intervention	Excluded in LES 15.1
Sheraz et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Sheraz et al., 2022	Wrong Study Design	Excluded in LES 15.1
Shimasaki, 2023	Wrong Study Design	Excluded in LES 15.2
Shimmei et al., 2020	Wrong Setting	Excluded in LES 15.2
Shishkin et al., 2021	Wrong Setting	Excluded in LES 15.2
Shrestha et al., 2021	Wrong Outcome	Excluded in LES 15.1
Shu et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Siddiqui et al., 2020	Wrong Study Design	Excluded in LES 15.1
Siebler et al., 2022	Wrong Intervention	Excluded in LES 15.1
Silva et al.,2023	Wrong Intervention	Excluded in LES 15.1
Sinha et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Snelling et al., 2022	Wrong Intervention	Excluded in LES 15.2
Sodiq et al., 2021	Wrong Study Design	Excluded in LES 15.2
Sojobi & Zayed, 2022	Wrong Study Design	Excluded in LES 15.2
Somsen et al., 2020	Wrong Intervention	Excluded in LES 15.1
Son & Jang, 2022	Wrong Outcome	Excluded in LES 15.2
Song et al., 2022	Wrong Study Design	Excluded in LES 15.2
Sousan et al., 2021	Wrong Intervention	Excluded in LES 15.2
Sousan et al., 2022	Wrong Intervention	Excluded in LES 15.1
Stavreva et al., 2022	Wrong Study Design	Excluded in LES 15.1
Sun et al.,2020	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Sunday & Sakugawa, 2020	Wrong Setting	Excluded in LES 15.2
Sumpaico-Tanchanco et al., 2022	Wrong Intervention	Excluded in LES 15.1
Szalański et al., 2023	Wrong Intervention	Excluded in LES 15.2
Takada et al., 2021	Wrong Intervention	Excluded in LES 15.2
Talaat et al., 2021	Wrong Intervention	Excluded in LES 15.1
Tamaddon et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Tan., et al 2024	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Tapia-Brito et al., 2023	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Tobisch et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Tham et al., 2019	Wrong Study Design	Excluded in LES 15.2
Thomas, 2021	Wrong Study Design	Excluded in LES 15.2
Thomberg et al., 2023	Wrong Setting	Excluded in LES 15.2
Thornton et al.,2022	Wrong Study Design	Excluded in LES 15.1
Thornton et al., 2022	Wrong Study Design	Excluded in LES 15.2
Tretiakow et al., 2021	Wrong Intervention	Excluded in LES 15.2
Truong et al., 2021	Wrong Study Design	Excluded in LES 15.2
Tupper et al., 2020	Wrong Intervention	Excluded in LES 15.1
Ueki et al., 2022	Wrong Setting	Excluded in LES 15.1
Ueki et al., 2022	Wrong Intervention	Excluded in LES 15.2
Ugarte-Anero et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Uhde et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ulhaq et al., 2020	Wrong Intervention	Excluded in LES 15.2

van Beest et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
van den Broek-Altenburg et al., 2021	Wrong Intervention	Excluded in LES 15.2
Vázquez-López et al., 2023	Wrong Study Design	Excluded in LES 15.2
Viana et al., 2022	Wrong Study Design	Excluded in LES 15.2
Villanueva et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Villers et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Vita et al.,2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Vlachokostas at el., 2022	Wrong Setting	Excluded in LES 15.1
Vlaskin, 2022	Wrong Study Design	Excluded in LES 15.2
Vouriot., et al 2021	Wrong Intervention	Excluded in LES 15.2
Wagner et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Waheeb at el., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Walker et al., 2022	Wrong Intervention	Excluded in LES 15.1
Wan et al., 2023	Wrong Intervention	Excluded in LES 15.2
Wang et al., 2020	Wrong Outcome	Excluded in LES 15.2
Wang et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wang et al., 2021	Wrong Study Design	Excluded in LES 15.2
Wang et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Wang et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Wang et al., 2022	Wrong Intervention	Excluded in LES 15.2
Wang et al., 2022	Wrong Outcome	Excluded in LES 15.2
Wang et al., 2022	Wrong Intervention	Excluded in LES 15.2
Wang et al., 2022	Wrong Study Design	Excluded in LES 15.2
Wang et al., 2022	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Wang et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wang et al., 2023	Wrong Outcome	Excluded in LES 15.2
Wang et al., 2024	Wrong Study Design	Excluded in LES 15.2
Ward et al., 2021	Wrong Intervention	Excluded in LES 15.2
Wei et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wei et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wei et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Werner et al., 2023	Wrong Setting	Excluded in LES 15.2
William et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wilson et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wolkoff, 2023	Wrong Study Design	Excluded in LES 15.2
Wong et al., 2023	Wrong Outcome	Excluded in LES 15.2
Woo et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Woodward et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Wu et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wu et al., 2021	Wrong Intervention	Excluded in LES 15.2
Wu et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Wu et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Wu et al., 2023	Wrong Setting	Excluded in LES 15.2
Xia et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Xiang et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Xie et al., 2020	Wrong Publication Date	Excluded in LES 15.2
Xie et al., 2021	Wrong Intervention	Excluded in LES 15.2
Xie et al., 2023	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Xu et al., 2020	Wrong Outcome	Excluded in LES 15.1
Xu et al., 2021	Wrong Intervention	Excluded in LES 15.1
Xu et al.,2022	Wrong Study Design	Excluded in LES 15.1
Yan et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Yan et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Yan et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Yan et al., 2023	Wrong Intervention	Excluded in LES 15.2
Yan et al., 2023	Wrong Outcome	Excluded in LES 15.2
Yan & Gao, 2021	Wrong Setting	Excluded in LES 15.2
Yang et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2

Yao et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Ye et al., 2022	Wrong Study Design	Excluded in LES 15.2
Yilmaz & Yilmaz, 2022	Wrong Outcome	Excluded in LES 15.2
Yoo et al.,2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1
Yoo et al., 2022	Wrong Setting	Excluded in LES 15.2
Yu et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Yuan et al., 2020	Wrong Outcome	Excluded in LES 15.2
Yun et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zacharias et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Zafar et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zang et al., 2021	Wrong Study Design	Excluded in LES 15.2
Zanganeh Kia et al., 2023	Wrong Intervention	Excluded in LES 15.2
Zaniboni et al., 2022	Wrong Study Design	Excluded in LES 15.1
Zargar et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Zargar et al., 2022	Wrong Intervention	Excluded in LES 15.1
Zauli-Sajani et al., 2022	Wrong Intervention	Excluded in LES 15.1
Zhai et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zhang et al., 2021	Wrong Outcome	Excluded in LES 15.1
Zhang et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zhang et al., 2021	Wrong Intervention	Excluded in LES 15.2
Zhang et al., 2021	Wrong Outcome	Excluded in LES 15.2
Zhang et al., 2021	Wrong Setting	Excluded in LES 15.2
Zhang et al., 2021	Wrong Outcome	Excluded in LES 15.2
Zhang & Wang, 2021	Wrong Study Design	Excluded in LES 15.2
Zhang et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zhang et al.,2022	Wrong Intervention	Excluded in LES 15.1
Zhang et al., 2022	Wrong Intervention	Excluded in LES 15.2
Zhang et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Zhang et al., 2022	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Zhang et al., 2023	Wrong Outcome	Excluded in LES 15.1
Zhang et al., 2023	Wrong Intervention	Excluded in LES 15.1
Zhang et al., 2023	Wrong Outcome	Excluded in LES 15.2
Zhang et al., 2023	Wrong Intervention	Excluded in LES 15.2
Zhang et al., 2024	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Zhao et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zhao et al., 2023	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Zhen et al., 2022	Wrong Study Design	Excluded in LES 15.2
Zheng et al., 2021	Wrong Study Design	Excluded in LES 15.2
Zheng et al., 2022	Wrong Setting	Excluded in LES 15.1
Zheng et al., 2023	Wrong Setting	Excluded in LES 15.2
Zhou et al., 2022	Wrong Setting	Excluded in LES 15.1
Zhou & Ji, 2021	Wrong Setting	Excluded in LES 15.1
Zhu, et al., 2020	Wrong Intervention	Excluded in LES 15.2
Zhu et al., 2020	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Zhu et al., 2022	Wrong Outcome	Excluded in LES 15.1
Zhu et al., 2022	Wrong Intervention	Excluded in LES 15.2
Zhuang et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.2
Zhuang et al., 2022	Modelling study (Low Confidence in Estimates)	Excluded in LES 15.2
Zivelongui & Lai, 2021	Wrong Outcome	Excluded in LES 15.2
Zivelongui et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1
Zoran et al., 2022	Wrong Outcome	Excluded in LES 15.2
Studies excluded in LES 15.1, Included in LES 15.2		
Aganovic et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Aganovic et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Arpino et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Barone et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1

		Included in LES 15.2
Corzo et al., 2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Cotman et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Das et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Faulkner et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Foster & Kinzel, 2021	Portable purifier modelling study with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Foat et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1 Included in LES 15.2
Ghoroghi et al., 2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Horve et al., 2022	Wrong Study Design	Excluded in LES 15.1 Included in LES 15.2
Jones et al., 2021	Wrong Population / Wrong Microorganism	Excluded in LES 15.1 Included in LES 15.2
Lu et al.,2022	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Mokhtari et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Moritz et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Myers et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1 Included in LES 15.2
O Donovan et al.,2023	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Pease et al., 2021	Portable purifier modelling study with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Risbeck et al., 2021	Portable purifier modelling study with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Sarhan et al., 2022	Wrong Population / Wrong Microorganism	Excluded in LES 15.1 Included in LES 15.2
Sha et al.,2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Shinohara et al.,2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Stabile et al., 2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Xu et al.,2021	Ventilation modelling studies with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Yan et al., 2022	Portable purifier modelling study with infection outcome	Excluded in LES 15.1 Included in LES 15.2
Zafari et al., 2022	Portable purifier modelling study with infection outcome	Excluded in LES 15.1 Included in LES 15.2
(92)	Wrong Population / Wrong Microorganism	Excluded in LES 15.1 Included in LES 15.2

Appendix 4: Definitions

Acceptable indoor air quality: Air in which there are no known contaminants at harmful concentrations as determined by knowledgeable authorities and with which a substantial majority (≥80%) of the people exposed do not express dissatisfaction (91).
Air changes per hour (ACH): The ratio of the volume of air flowing through a space in a certain period of time (the airflow rate) to the volume of that space (the room volume). This ratio is expressed as the number of ACH (91).
Air change/exchange rate (ACR or AER): volume of air supplied to and removed from a space, via mechanical systems or through the building enclosure, per unit of time divided by the volume of the space, using the same units for volume such that the unit is inverse time. (91).
Air filtration: refers to removing unwanted matter (e.g., particles) from the air stream by passing the airflow through fine mesh obstructions. In principle, some fraction of the unwanted matter will stay upstream of the filter and relatively cleaner air will flow downstream of the filter.
Air purification: The process of removing contaminants, such as dust, pollen, mold, bacteria, viruses, and VOCs, from the air.
Air mixing: The degree to which air supplied to a room mixes with the air already in the room, usually expressed as a mixing factor. This factor varies from 1 (for perfect mixing) to 10 (for poor mixing). It is used as a multiplier to determine the actual airflow required (i.e., the recommended ACH multiplied by the mixing factor equals the actual ACH required) (91).
ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc (91).
Diffuser: The grille plate that disperses the air stream coming into the conditioned air space (91).
Exhaust air: Air removed from a space and not reused therein (91).
Dilution ventilation: Dilution ventilation mixes contaminated air with clean air, diluting the resultant air to a lower concentration of the contaminant to avoid adverse health effects. Since a safe level of virus exposure has not been established, mixing air to dilute it is most protective if the amount of clean dilution air is maximized (92).
Displacement ventilation (DV): DV keeps overall room air mixing to a minimum and instead pushes the contaminated air away from the breathing zone in as close to a laminar, plug flow as possible, replacing contaminated room air parcels with clean ones (92).
Filters: These are devices that remove contaminants from the air. They are categorized into different classes based on their efficiency in removing particles of various sizes. The ASHRAE ratings include MERV, E, G, H, U, and other classes. Some types of filters include Fiberglass Filters (MERV-1to4), Pleated Filters (MERV-5 to 8), High-Efficiency Particulate Air (HEPA) Filters (MERV-17 to 20), Electrostatic Filters, Activated Carbon Filters, UV-C Filters.
Filter ratings or Minimum Efficiency Reporting Values (MERV): report a filter's ability to capture larger particles between 0.3 and 10 microns.
Fixed room-air HEPA recirculation systems: Nonmobile devices or systems that remove airborne contaminants by recirculating air through a HEPA filter. These may be built into the room and permanently ducted or may be mounted to the wall or ceiling within the room. In either situation, they are fixed in place and are not easily movable (91).
Heating, Ventilating, and Air Conditioning (HVAC): The technology of indoor and vehicular environmental comfort, which aims to provide thermal comfort and acceptable indoor air quality.
HEPA filter: High Efficiency Particulate Air (HEPA) filters capable of removing 99.97% of particles 0.3 μm in diameter and may assist in controlling the transmission of airborne disease agents. These filters may be used in ventilation systems to remove particles from the air or in personal respirators to filter air before it is inhaled by the person wearing the respirator. The use of HEPA filters in ventilation systems requires expertise in installation and maintenance. To test this type of filter, 0.3 μm particles of dioctyl phthalate (DOP) are drawn through the filter. Efficiency is calculated by comparing the downstream and upstream particle counts. The optimal HEPA filter allows only three particles to pass through for every 10,000 particles that are fed to the filter (91).
Hybrid ventilations systems: systems that use both natural ventilation and mechanical systems (93)
HVAC: Heating, Ventilation, Air Conditioning (91).
Indoor Air Quality (IAQ): Refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants (92).
Laminar flow: HEPA-filtered air that is blown into a room at a rate of 90 ± 10 feet/min in a unidirectional pattern with 100 ACH–400 ACH (91).
Natural ventilation: The movement of outdoor air into a space through intentionally provided openings (i.e., windows, doors, or nonpowered ventilators) (91).

Negative pressure: Air pressure differential between two adjacent airspaces such that air flow is directed into the room relative to the corridor ventilation (i.e., room air is prevented from flowing out of the room and into adjacent areas) (91).
Outdoor air: Air taken from the external atmosphere and, therefore, not previously circulated through the ventilation system (91).
Particulate matter (particles): A state of matter in which solid or liquid substances exist in the form of aggregated molecules or particles. Airborne particulate matter is typically in the size range of 0.01–100 µm diameter (91).
Portable Air Cleaners (PAC): also known as air purifiers or air sanitizers, are designed to filter the air in a single room or area.
Positive pressure: Air pressure differential between two adjacent air spaces such that air flow is directed from the room relative to the corridor ventilation (i.e., air from corridors and adjacent areas is prevented from entering the room) (91).
Quanta levels: The amount of infectious material to infect 1−(1/e) of the people in an enclosed space. A physical measure of the infectious material present, which effectively indicates both the quantity and pathogenicity of an infectious material present in the air (94).
Recirculated air: Air removed from the conditioned space and intended for reuse as supply air (91).
Relative humidity (RH): The ratio of the amount of water vapor in the atmosphere to the amount necessary for saturation at the same temperature. RH is expressed in terms of percent and measures the percentage of saturation. At 100% relative humidity, the air is saturated. The RH decreases when the temperature is increased without changing the amount of moisture in the air (91).
Respiratory particles: Particles of respirable size generated by humans that have the potential to remain viable and airborne for extended periods in the indoor environment, and may contain infectious microorganisms. These particles can be generated by breathing, talking, shouting, sneezing, coughing and laughing.

Supply air: Air that is delivered to the conditioned space and used for ventilation, heating, cooling, humidification, or dehumidification (91).
Total suspended particulate matter: The mass of particles suspended in a unit of volume of air when collected by a high-volume air sampler (91).
Ultraviolet germicidal irradiation (UVGI): The use of ultraviolet radiation to kill or inactivate microorganisms (91).
Ventilation: refers to dilution of indoor air with outdoor air. Air dilution can occur through natural means (e.g., opening windows or doors) or mechanical means (e.g., Heating, Ventilation and Air Condition [HVAC] systems). Improving ventilation helps to limit the number of infectious particles indoors by diluting indoor air with outdoor air that has fewer infectious particles.
Ventilation, dilution: An engineering control technique to dilute and remove airborne contaminants by the flow of air into and out of an area. Air that contains droplet nuclei is removed and replaced by contaminant-free air. If the flow is sufficient, droplet nuclei become dispersed, and their concentration in the air is diminished (91).
Ventilation, local exhaust: Ventilation used to capture and removed airborne contaminants by enclosing the contaminant source (the patient) or by placing an exhaust hood close to the contaminant source (91).
v/v: Volume to volume. This term is an expression of concentration of a percentage solution when the principle component is added as a liquid to the diluent (91).
w/v: Weight to volume. This term is an expression of concentration of a percentage solution when the principle component is added as a solid to the diluent (91).

Appendix 5: Data extraction form

Last updated March 28th 2024

Data extraction form (Table 1)

Data extraction category	Data extraction element
Reference details	Study Title First author Date of publication PMDI or DOI Country of publication Funding
Study characteristics	Aim Design Methods Intervention Frequency Comparator Frequency Cointerventions Agents assessed
Population characteristics	Sample description. Any PROGRESS+ considerations? N Female (%) Setting
Results	Key outcomes Time of reporting Adjusted (Regression, stratification, matching and associated variables) Y or N, and explain. Summary of key findings in relation to outcome

Appendix 6: Critical Appraisal Process for Assessment of Public Health Measures for COVID-19

Last updated March 28th 2024

For all epidemiological studies reporting on effectiveness of ventilation in reducing COVID-19 infections RoB will be assessed.

Critical appraisal tool for cohort studies

Study Characteristics that may introduce bias	Description
Study design **ROBINS-I: Bias in selection of participants into study** People who choose to use a cleaning/disinfection intervention may differ in risk-taking and health-seeking behavior from people who do not choose to use a cleaning/disinfection intervention	**Were both study groups recruited from the same population during the same time period?** Examples and typical judgment: ● Same country/province/state measured at same time = moderate ● Same or different country/province/state measured at a different time during pandemic = serious ● Same or different country/province/state measured at a different time prior to pandemic = critical ● Not applicable = no information **Were the RIDs protective interventions implemented prior to period of data collection?** (Prevalent users) Examples and typical judgment: ● Start of data collection at same time as implementation with no prevalent users = low ● Prevalent users likely but appropriately controlled for = moderate ● Not addressed and highly likelihood of prevalent users = critical **Were the study groups balanced with respect to participant adherence (based on internal and external factors unrelated to RIDS)?** (For example, people who are less likely to adhere to PHSMs anyway may be more likely to be exposed to RIDS and require quarantine & isolation but then are less likely to adhere. Similar for e.g., people who work are essential workers without paid time off.) Examples and typical judgment: ● Adherence confirmed to be same in both groups at start of study = low ● Difference in adherence likely but appropriately controlled for = moderate ● Not addressed and highly likelihood of difference in adherence = critical ● Not applicable = no information
Method for confirming the use of cleaning/disinfection products and strategies. **ROBINS-I: Bias in classification of interventions** An appropriate comparison of interventions requires that the interventions are well defined.	**Was the method for confirming the intervention (e.g., type, setting, dose, frequency, intensity and/or timing of intervention) clearly defined and applied consistently across study samples (e.g., districts within a country)?** Examples and typical judgment: ● Well defined and solely based on information collected at time of intervention = low ● Well defined but some aspects of assignment of intervention status determined retrospectively = moderate ● Intervention status not well defined or applied inconsistently = serious ● Not addressed = critical ● Not applicable = no information **In periods of co-occurring interventions, do the authors clearly classify each individual intervention?**

	Examples and typical judgment: ● All co-interventions well defined and solely based on information collected at time of intervention = low ● Co-intervention classification well defined but some aspects of assignment of status determined retrospectively = moderate ● Co-intervention classification not well defined or applied inconsistently = serious ● Not addressed and co-interventions present = critical ● Not applicable = no information **Does classification into intervention/control group depend on self-report in a way that might introduce bias?** (For example, where negative consequences of providing truthful responses may lead to negative consequences e.g., self-reporting RIDS symptoms would trigger 14-day quarantine and loss of income) Examples and typical judgment: ● Not reliant on self-report = low ● Reliant on self-report but appropriately controlled for/analyzed separately = moderate ● Not addressed and reliant on self-report = critical ● Not applicable = no information **For household transmission studies, was it clear that exposure to the index case was the most likely the only exposure to RIDS for household or close contacts?** Examples and typical judgment: ● All participants isolated to same house or hospital prior to index case identification = low ● All participants isolated to same house or hospital from time of index case identification = moderate ● High risk occupational and social exposures likely and not accounted for = serious ● Not addressed = critical ● Not applicable = no information
Accounting for calendar time **ROBINS-I: Bias due to confounding (time-varying confounding)** Accounting for calendar time reduces bias in outcome estimation due to differences in intervention accessibility and risk of exposure over time.	**Did the study adjust for calendar time (implications for circulating variant, season)?**** Examples and typical judgment: ● Studies with explicit mention of calendar time adjustment if there are concerns about risk, prevalence, outbreaks = low ● Use of time-varying statistics without explicit mention of adjustment for calendar time = moderate ● Not taken into account but no concerns about risk exposure affecting the intervention = moderate ● Not taken into account and concerns about risk exposure affecting the intervention = critical ● Not applicable = no information
Adjustment for prognostic factors **ROBINS-I: Bias due to confounding** Adjustment for prognostic factors for RIDS transmission, and the intervention, such as age, gender, socioeconomic factors, occupation (HCW, LTC), use of other PHSMs, number of persons	**Did the study adjust for demographics, prognostic factors and other relevant factors?**** Examples and typical judgment: ● All known important confounding domains measured and sufficient adjustment for all considered important prognostic factors = moderate ● At least one known important domain not measured or controlled for (e.g., socioeconomic status, number of persons according to the setting) = serious ● No adjustment for other relevant factors = critical ● Not applicable = no information

in the setting (in studies where population is not an individual), prior COVID-19 infection within the past 90 days, close contact with index case, etc.	**Did the study adjust for other RIDS protective interventions (including vaccination)?**** <u>Examples and typical judgment</u>: ● All known important interventions controlled for = moderate ● One co-intervention not controlled for = serious ● Multiple co-interventions with no controlling or adjustment = critical ● Not applicable = no information **Were participants free of confirmed RIDS infection at the start of the study?**** <u>Examples and typical judgment</u>: ● Negative RIDS status of both groups known at study start (lab confirmed) = low ● RIDS status of intervention group known but unclear for control group <u>OR</u> RIDS status of both groups known by self-report only = serious ● Unclear or high likelihood pts had RIDS at start of study = critical ● Not applicable = no information
Testing frequency **ROBINS-I: Bias in measurement of outcomes** Similar frequency of testing between groups reduces risk of bias introduced by detecting asymptomatic infection in one group but not in another (e.g., when only one group undergoes surveillance screening).	**Was the outcome of RIDS confirmed by laboratory testing?**** <u>Examples and typical judgment</u>: ● All participants had PCR = low ● Most participants had PCR = moderate ● All participants had other RIDs test = serious ● Only sample or subset of population had PCR = serious ● Not reported = critical ● Only sample or subset of population had other RIDs test = serious ● Not applicable = no information **If the outcomes were derived from databases, were the databases constructed specifically for the collection of RIDS data?**** <u>Examples and typical judgment</u>: ● National/state/province level surveillance database or specifically for RIDS = low ● Database for non-RIDS purpose with individual level data (e.g., health records, employee records) = moderate ● Database for non-RIDS purpose without individual level data = serious ● No or unclear = critical ● Not applicable = no information **Were appropriate tools/methods with validated/justified cut-points used to determine outcomes of interest (other than RIDS infection/transmission which is covered under laboratory testing)? **** <u>Examples and typical judgment</u>: ● Objective validated measure used consistently across all groups = low ● Objective measure applied but validation uncertain = moderate ● Outcomes solely dependent on self-report without a validated measure = serious ● Not reported = critical **If the outcome was self-reported, did the authors attempt to control for social desirability?**** <u>Examples and typical judgment</u>: ● Outcome not influenced by social desirability = low ● Attempt made to control for social desirability = moderate ● Not reported and outcome likely to be influenced by social desirability = critical ● Not applicable = no information **Was the frequency of testing for the outcome different between the study groups?**

	Examples and typical judgment: ● No difference in frequency of testing between groups = low ● Some differences but rationale appropriate = moderate ● Routinely done more frequently in one group more than the other = critical **If outcome was observed, was there more than one assessor and if so, was interrater agreement reported?** Examples and typical judgment: ● Reported with excellent agreement = low ● Reported with moderate agreement = moderate ● Reported with low agreement = serious ● Not reported = critical
Missing data **ROBINS-I: Bias due to missing data** Missing data can introduce bias due to differences in the comparison groups that are related to the outcome. Evidence for robustness may come from how missing data was handled in the study analysis.	**Was outcome data at the end of the study period available for all or nearly all participants?** Examples and typical judgment: ● No missing data = low ● Missing data did not differ between groups or was accounted for by appropriate statistical methods = moderate ● Critical differences in missing data between groups = critical **Were participants excluded due to missing data?** Examples and typical judgment: ● No exclusions due to missing data = low ● Participants excluded due to missing data, but rationale was appropriate and applied the same across all groups = moderate ● Participants excluded based on data missing unevenly across groups = critical
Bias due to deviations from intended intervention? **ROBINS-I: Bias due to deviations from intended intervention**	**Did the authors assess adherence to the protective behaviours/interventions after intervention implementation?**** Examples and typical judgment: ● Adherence verified in all study participants = low ● Adherence verified in at least a subset of each study group or appropriately adjusted for = moderate ● Reliant on self-report of adherence without verification or adjustment = serious ● Not addressed = critical ● Not applicable = no information

****relevant to single arm cohort studies**

Critical appraisal checklist for cross-sectional studies

Questions	Possible responses
1. Were the criteria for inclusion in the sample clearly defined? The authors should provide clear inclusion and exclusion criteria that they developed prior to recruitment of the study participants. The inclusion/exclusion criteria should be specified (e.g., risk, stage of disease progression) with sufficient detail and all the necessary information critical to the study.	NA = not applicable; Y = yes; N = no; U = unclear
2. Were the study subjects and the setting described in detail? The study sample should be described in sufficient detail so that other researchers can determine if it is comparable to the population of interest to them. The authors should provide a clear description of the population from which the study participants were selected or recruited, including demographics, location, and time period.	
3. Was the exposure measured in a valid and reliable way? The study should clearly describe the method of measurement of exposure. Assessing validity requires that a 'gold standard' is available to which the measure can be compared. The validity of exposure measurement usually relates to whether a current measure is appropriate or whether a measure of past exposure is needed. Reliability refers to the processes included in an epidemiological study to check repeatability of measurements of the exposures. These usually include intra-observer reliability and inter-observer reliability.	
4. Were objective, standard criteria used for measurement of the condition? It is useful to determine if patients were included in the study based on either a specified diagnosis or definition. This is more likely to decrease the risk of bias. Characteristics are another useful approach to matching groups, and studies that did not use specified diagnostic methods or definitions should provide evidence on matching by key characteristics.	
5. Were confounding factors identified? Confounding has occurred where the estimated intervention exposure effect is biased by the presence of some difference between the comparison groups (apart from the exposure investigated/of interest). Typical confounders include baseline characteristics, prognostic factors, or concomitant exposures (e.g. smoking). A confounder is a difference between the comparison groups, and it influences the direction of the study results. A high-quality study at the level of cohort design will identify the potential confounders and measure them (where possible). This is difficult for studies where behavioral, attitudinal or lifestyle factors may impact on the results.	
6. Were strategies to deal with confounding factors stated? Strategies to deal with effects of confounding factors may be dealt within the study design or in data analysis. By matching or stratifying sampling of participants, effects of confounding factors can be adjusted for. When dealing with adjustment in data analysis, assess the statistics used in the study. Most will be some form of multivariate regression analysis to account for the confounding factors measured.	
7. Were the outcomes measured in a valid and reliable way? ￼ Read the methods section of the paper. If for e.g. lung cancer is assessed based on existing definitions or diagnostic criteria, then the answer to this question is likely to be yes. If lung cancer is assessed using observer reported, or self-reported scales, the risk of over- or under-reporting is increased, and objectivity is compromised. Importantly, determine if the measurement tools used were validated instruments as this has a significant impact on outcome assessment validity. Having established the objectivity of the outcome measurement (e.g. lung cancer) instrument, it's important to establish how the measurement was conducted. Were those involved in collecting data trained or educated in the use of the instrument/s? (e.g. radiographers). If there was more than one data collector, were they similar in terms of level of education, clinical or research experience, or level of responsibility in the piece of research being appraised?	
8. Was appropriate statistical analysis used? As with any consideration of statistical analysis, consideration should be given to whether there was a more appropriate alternate statistical method that could have been used. The methods section should be detailed enough for reviewers to identify which analytical techniques were used (in particular, regression or stratification) and how specific confounders were measured. For studies utilizing regression analysis, it is useful to identify if the study identified which variables were included and how they related to the outcome. If stratification was the analytical approach used, were the strata of analysis defined by the specified variables? Additionally, it is also important to assess the appropriateness of the analytical strategy in terms of the assumptions associated with the approach as differing methods of analysis are based on differing assumptions about the data and how it will respond.	

Critical appraisal tool for case-control studies

Questions	Possible responses
Were the groups comparable other than presence of disease in cases or absence of disease in controls? The control group should be representative of the source population that produced the cases. This is usually done by individual matching; wherein controls are selected for each case on the basis of similarity with respect to certain characteristics other than the exposure of interest. Frequency or group matching is an alternative method. Selection bias may result if the groups are not comparable.	NA = not applicable; Y = yes; N = no; U = unclear
Were cases and controls matched appropriately? As in item 1, the study should include clear definitions of the source population. Sources from which cases and controls were recruited should be carefully looked at. For example, cancer registries may be used to recruit participants in a study examining risk factors for lung cancer, which typify population-based case control studies. Study participants may be selected from the target population, the source population, or from a pool of eligible participants (such as in hospital-based case control studies).	
Were the same criteria used for identification of cases and controls? It is useful to determine if patients were included in the study based on either a specified diagnosis or definition. This is more likely to decrease the risk of bias. Characteristics are another useful approach to matching groups, and studies that did not use specified diagnostic methods or definitions should provide evidence on matching by key characteristics. A case should be defined clearly. It is also important that controls must fulfil all the eligibility criteria defined for the cases except for those relating to diagnosis of the disease.	
Was exposure measured in a standard, valid and reliable way? The study should clearly describe the method of measurement of exposure. Assessing validity requires that a 'gold standard' is available to which the measure can be compared. The validity of exposure measurement usually relates to whether a current measure is appropriate or whether a measure of past exposure is needed. Case control studies may investigate many different 'exposures' that may or may not be associated with the condition. In these cases, reviewers should use the main exposure of interest for their review to answer this question when using this tool at the study level. Reliability refers to the processes included in an epidemiological study to check repeatability of measurements of the exposures. These usually include intra-observer reliability and inter-observer reliability.	
Was exposure measured in the same way for cases and controls? As in item 4, the study should clearly describe the method of measurement of exposure. The exposure measures should be clearly defined and described in detail. Assessment of exposure or risk factors should have been carried out according to same procedures or protocols for both cases and controls.	
Were confounding factors identified? Confounding has occurred where the estimated intervention exposure effect is biased by the presence of some difference between the comparison groups (apart from the exposure investigated/of interest). Typical confounders include baseline characteristics, prognostic factors, or concomitant exposures (e.g. smoking). A confounder is a difference between the comparison groups, and it influences the direction of the study results. A high-quality study at the level of case control design will identify the potential confounders and measure them (where possible). This is difficult for studies where behavioral, attitudinal or lifestyle factors may impact on the results.	
Were strategies to deal with confounding factors stated? Strategies to deal with effects of confounding factors may be dealt within the study design or in data analysis. By matching or stratifying sampling of participants, effects of confounding factors can be adjusted for. When dealing with adjustment in data analysis, assess the statistics used in the study. Most will be some form of multivariate regression analysis to account for the confounding factors measured. Look out for a description of statistical methods as regression methods such as logistic regression are usually employed to deal with confounding factors/ variables of interest.	
Were outcomes assessed in a standard, valid and reliable way for cases and controls? Read the methods section of the paper. If for e.g. lung cancer is assessed based on existing definitions or diagnostic criteria, then the answer to this question is likely to be yes. If lung cancer is assessed using observer reported, or self-reported scales, the risk of over- or under-reporting is increased, and objectivity is compromised. Importantly, determine if the measurement tools used were validated instruments as this has a significant impact on outcome assessment validity. Having established the objectivity of the outcome measurement (e.g. lung cancer) instrument, it's important to establish how the measurement was conducted. Were those involved in collecting data trained or educated in the use of the instrument/s? (e.g. radiographers). If there was more than one data collector, were they similar in terms of level of education, clinical or research experience, or level of responsibility in the piece of research being appraised?	

Was the exposure period of interest long enough to be meaningful? It is particularly important in a case control study that the exposure time was sufficient enough to show an association between the exposure and the outcome. It may be that the exposure period may be too short or too long to influence the outcome.	
Was appropriate statistical analysis used? As with any consideration of statistical analysis, consideration should be given to whether there was a more appropriate alternate statistical method that could have been used. The methods section should be detailed enough for reviewers to identify which analytical techniques were used (in particular, regression or stratification) and how specific confounders were measured. For studies utilizing regression analysis, it is useful to identify if the study identified which variables were included and how they related to the outcome. If stratification was the analytical approach used, were the strata of analysis defined by the specified variables? Additionally, it is also important to assess the appropriateness of the analytical strategy in terms of the assumptions associated with the approach as differing methods of analysis are based on differing assumptions about the data and how it will respond.	

For all modelling and simulation studies reporting on ventilation effectiveness, a completeness and appropriateness assessment was applied using a self-constructed tool.

Question
Are the description of the population and interventions adequate? The description of the population and demographic characteristics important to the model being evaluated should be clearly described. The description of the characteristics of the intervention, especially the aspects that affect the model, should be clearly described.
Is the description of the model used complete and appropriate? The purpose of the model and the parameters used in the model should be clearly stated.
Were all assumptions assumed in the model published? It should be assessed whether there is an explicit mention of all assumptions underlying the model or related to the parameters of the model, such as viral load, transmission rates or specific occupant behaviors, etc.
Were the formulas associated with the model published? Mathematical formulas or algorithms implemented in the models should be included in the publication.
Are the results and conclusions consistent? The consistency and validity of the results and conclusions will ultimately depend on the accuracy and transparency with which the model was applied, including the specific modifications of the study and the robustness of the data collected, however, if the results and conclusions are not consistent with the objectives and scope of the model, they will not be considered consistent.