REALM PROJECT
REopening Archives, Libraries, and Museums

Briefing: Vaccines, Variants, and Ventilation

A Briefing on Recent Scientific Literature Focused on SARS-CoV-2 Vaccines and Variants, Plus the Effects of Ventilation on Virus Spread

Dates of Search: 01 January 2021 through 29 November 2021

Published: 16 December 2021

OCLC · Institute of Museum and Library Services · BATTELLE

INTRODUCTION

Purpose of This Briefing

- Access to the latest scientific research is critical as libraries, archives, and museums (LAMs) work to sustain modified operations during the continuing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic.
- As an emerging event, the SARS-CoV-2 pandemic continually presents new challenges and scientific questions. At present, **SARS-CoV-2 vaccines and variants of concern (VOCs) in the US** are two critical areas of focus. The effects of **ventilation-based interventions on the spread of SARS-CoV-2** are also an interest area for LAMs. This briefing provides key information and results from the latest scientific literature to help inform LAMs making decisions related to these topics.

How to Use This Briefing: This briefing is intended to provide timely information about SARS-CoV-2 vaccines, variants of concern, and ventilation to LAMs and their stakeholders. Due to the evolving nature of scientific research on these topics, the information provided here is not intended to be comprehensive or final. As such, this briefing should be used in conjunction with other timely resources to ensure decision-making reflects the latest scientific understanding. Continual re-evaluation of SARS-CoV-2 policies is highly recommended as new scientific discoveries are published.

About This Briefing

- Battelle conducted a systematic search of scientific literature about SARS-CoV-2 vaccines, variants, and ventilation. This briefing summarizes those findings.
- Research questions:
    1. What implications does SARS-CoV-2 vaccination in the US have for public health interventions and policies, especially related to indoor environments?
    2. How do SARS-CoV-2 variants of concern currently circulating in the US differ from the original strain and other variants in terms of spread, transmissibility, surface attenuation, and effectiveness of public health interventions?
    3. What effects do ventilation and ventilation-based interventions (e.g., heating, ventilation, and air conditioning systems (HVAC)) have on the spread of SARS-CoV-2 in indoor environments?
- Dates of search: 01 January 2021 to 29 November 2021. Newest items labeled "[New]"
- Additional information about the methods used to conduct the literature search and create this briefing is included later in the document.

About REALM

REopening Archives, Libraries, and Museums (REALM) is a research project conducted by OCLC, the Institute of Museum and Library Services (IMLS), and Battelle to produce and distribute science-based COVID-19 information that can aid local decision-making regarding operations of archives, libraries, and museums.

View reports published by REALM.

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BACKGROUND INFORMATION: VACCINES AND VARIANTS

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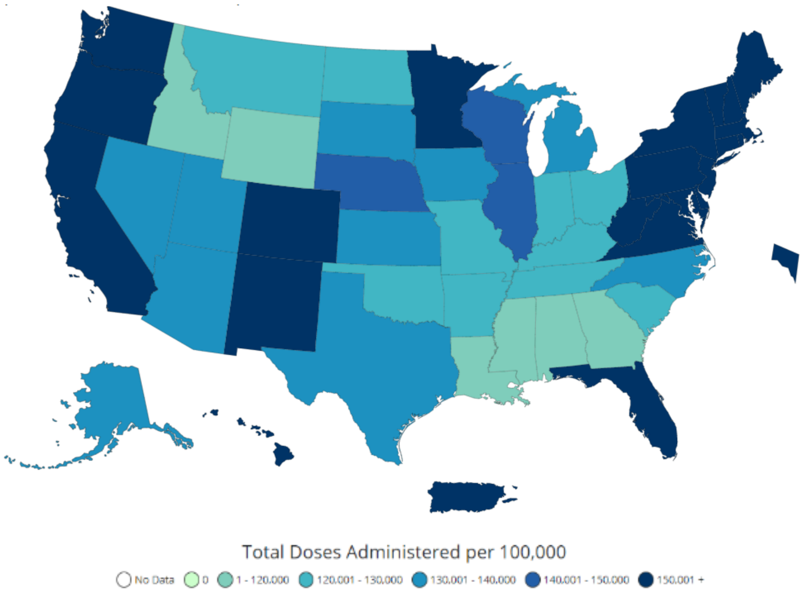
SARS-CoV-2 Vaccines

- The CDC reports updated vaccination numbers daily on a COVID-19 data tracker.[1]
- Three safe and effective vaccines are being distributed, two under the US FDA Emergency Use Authorization and one with full FDA approval: [2, 3]
  - Pfizer-BioNTech: 2-dose series, 21 days apart [4]
    - Full FDA approval on 23 August 2021 for people ages 16 and older.[3]
  - Moderna: 2-dose series, 28 days apart.[4]
  - Janssen (Johnson & Johnson) (J&J): Single dose.[5]
- CDC recommends individuals get the first vaccine that is available for their age group.[6]
- The US government has made vaccines free, and they are widely available now.[7]

Total Doses Administered Reported to the CDC by State/Territory per 100,000 of the Total Population (as of 14 December 2021)



**Vaccination rates by county are also available

To find local vaccination sites: visit Vaccines.gov, text a zip code to 438829, or call 800-232-0233.

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SARS-CoV-2 Vaccines

- CDC recommends that everyone age 5 or older receive a COVID-19 vaccine.[7]
  - [New] CDC now recommends that everyone age 18 and older receive a booster vaccination. Learn more about when to receive a booster shot and which booster shot to receive.[8]
  - CDC recommends an additional dose of mRNA vaccine (e.g., Pfizer or Moderna) at least 28 days after the second dose for people with moderately or severely compromised immune systems.[9]
  - CDC noted increased reports of heart-related inflammation in teens and young adults after COVID-19 vaccination, but COVID-19 vaccination is still recommended for everyone age 12 or older because benefits continue to outweigh risks.[4]
  - On 13 July 2021, FDA reported an observed increased risk of Guillain-Barré Syndrome (GBS) after J&J vaccination. Vaccine fact sheets now note that adverse events suggest increased risk of GBS and J&J vaccine recipients with GBS symptoms should seek medical attention.[10]
- CDC continues to review infection rates across the country and release guidance on precautions that both vaccinated and non-vaccinated people should take to stop the spread of COVID-19.[11]
- Lists of what may and may not be safe to change after full vaccination are on the CDC website.

Variants of SARS-CoV-2

What is a Variant?

- **Viruses inherently replicate, which can result in genetic changes or mutations**. After enough mutations occur, the new version is called a variant. Multiple SARS-CoV-2 variants have been found in the US and abroad.
- Sometimes new variants emerge and disappear, and other times new variants emerge and persist.[12]

Types of Variants[13]

- There are four categories of variants classified by the US government. The types differ based on the possibility of the variant to affect people negatively, such as increased transmissibility. In order from least to most negative effects:
  - Variants Being Monitored (VBM)
  - Variants of Interest (VOI)
  - Variants of Concern (VOC)
  - Variants of High Consequence (VOHC)
- As of this report, in the US there are 10 VBM, 0 VOI, 2 VOC, and 0 VOHC.[13]

Why is it important to track variants?

Monitoring variants can help find out:

- How the virus changes over time into new variants
- How these changes affect aspects of the virus
- How the changes might impact health.[13]

Variants of SARS-CoV-2

CDC Variants of Concern (VOC)

"A variant for which there is evidence of an increase in transmissibility, more severe disease (e.g., increased hospitalizations or deaths), significant reduction in neutralization by antibodies generated during previous infection or vaccination, reduced effectiveness of treatments or vaccines, or diagnostic detection failures."[13]

Information about reported cases of variants by region and state is available from the CDC.

Current CDC Variants of Concern in the US (as of 14 December 2021)[12]

Variant	WHO Label	First Detected	Other Names
B.1.617.2	Delta	India	20A/S:478K
B.1.1.529 [New]	Omicron	South Africa	21K

[New] **Note: CDC designated Omicron as a VOC on 30 Nov 2021, and the first case in the US was confirmed on 1 Dec 2021.[14]**

What does neutralization mean?
Neutralization is when antibodies, part of the body's defense, bind to a virus and block infection. Vaccines cause the body to build up the antibodies that inhibit viruses.[15]

SUMMARY OF FINDINGS: SYSTEMATIC SEARCH OF SCIENTIFIC LITERATURE ABOUT SARS-COV-2 VACCINES, VARIANTS OF CONCERN, AND VENTILATION

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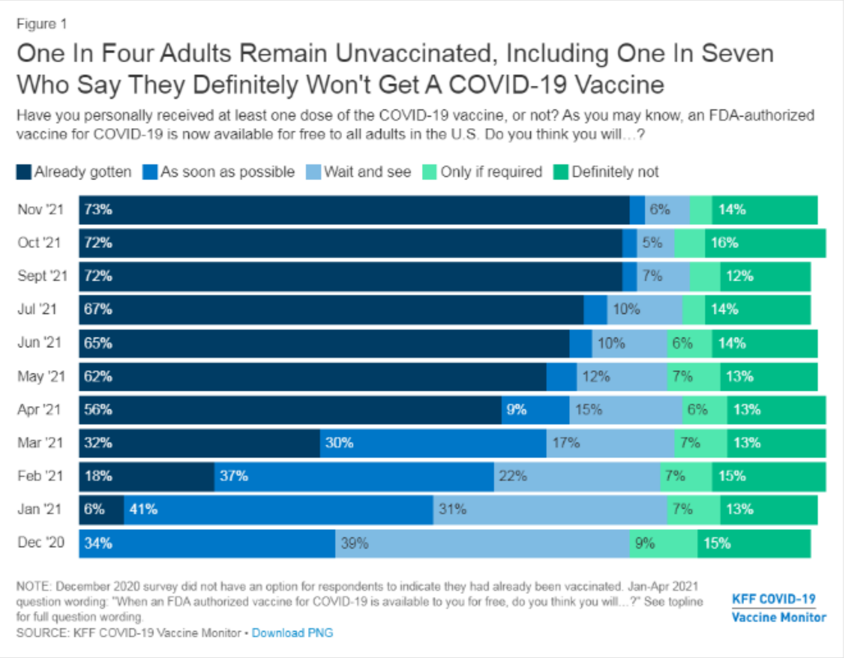
Studies About SARS-CoV-2 Vaccines

Studies About SARS-CoV-2 Vaccines

The Kaiser Family Foundation COVID-19 Vaccine Monitor is an ongoing research project that utilizes surveys and qualitative data to track the US public's attitudes and experiences with COVID-19 vaccines.[16]



[New] Key Findings from November 2021 Monitor

- COVID-19 vaccine uptake among US adults has slowed. One in four adults remains unvaccinated and one in seven reports that they definitely will not get vaccinated, a number that has held steady since December of last year.
- The share of fully vaccinated adults who report receiving a booster dose has increased, with 23% of fully vaccinated adults reporting receiving a COVID-19 booster dose.
- Older adults are most likely to report receiving a booster dose. While majorities across all demographic groups have received a COVID-19 vaccine, a recent KFF analysis found partisanship is now the strongest self-identifying predictor of being unvaccinated. A quarter of Republicans (26%) continue to say they will "definitely not" get a COVID-19 vaccine.
- 36% of pregnant women or women trying to become pregnant remain unvaccinated. One reason is because 57% say they are not confident the COVID-19 vaccines are safe for pregnant women.

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Studies About SARS-CoV-2 Vaccines

Impact of Vaccines and Safety

- Studies continue to show that COVID-19 vaccines offer protection against the infectiousness, transmissibility, and disease burden of SARS-CoV-2,[18-35] [New] including among adolescents[36,37] [New] and children[38,39] [New]
  - [New] In a case-control study of 4,513 hospitalized adults in 18 US states, vaccination with an mRNA COVID-19 vaccine was significantly less likely among patients hospitalized with COVID-19 who died or underwent mechanical ventilation.[40]
  - [New] Among persons aged ≥12 years enrolled in a health plan in the northwest U.S., unvaccinated persons with SARS-CoV-2 infection were about twice as likely as vaccinated persons to receive care in the emergency department or be hospitalized.[37]
  - A study in Health Affairs estimates that vaccinations against COVID-19 may have averted up to 140,000 deaths in the US as of May 2021.[41]
- Vaccine safety is assessed during the development process and is still continuously monitored.[42-50] While states have expanded vaccine eligibility, surveys continue to show “vaccine hesitancy” remains a concern for ensuring equitable vaccination coverage.[51,52]
- Rare serious adverse events have been reported after COVID-19 vaccination, including myocarditis, Guillain-Barré syndrome (GBS), and thrombosis with thrombocytopenia syndrome (TTS).[53]
  - Myocarditis, in particular, has been found to be more prevalent in young men.[54-56]
  - The Advisory Committee on Immunization Practices (ACIP) determined that the benefits of COVID-19 vaccination in preventing COVID-19 morbidity and mortality outweigh the risks for these rare serious adverse events.[53]

Studies About SARS-CoV-2 Vaccines

Vaccine Hesitancy

- Factors potentially related to vaccine hesitancy include concerns over vaccine safety, trust in government recommendations, perceived political interference, education, income, race/ethnicity, perceived threat of COVID-19, and experience with racial discrimination.[57-64]

Vaccine Booster Shots

- Although the two-dose regimen of the Pfizer-BioNTech vaccine remains effective against severe disease and hospitalizations, clinical trial data show that a third booster dose (administered 7 to 9 months after primary two-dose series) could provide prolonged protection.[65] This is particularly important for those at highest risk, including the immunocompromised.[66]
- Israeli studies have found that booster shots are effective in both elderly populations and the general population.[67,68]

Studies About SARS-CoV-2 Vaccines

Breakthrough Infections After Vaccination

- Fully vaccinated individuals needing emergency care due to COVID-19 is a rare occurrence. [New] A meta-analysis found a decreased incidence of COVID-19 infection as well as decreased incidence of hospitalization, ICU admission and deaths, amongst vaccinated health care workers.[69]
    - The overall pooled proportion of COVID-19 infections: 2.3%: Partially vaccinated healthcare workers, 1.3%: Fully vaccinated healthcare workers, and 10.1%: Unvaccinated healthcare workers.[69]
- One article reported that when hospital treatment is required; however, elderly patients with comorbidities are at high risk for serious illness regardless of vaccination status.[70]
- Breakthrough infections tend to have milder symptoms and shorter periods of illness. One study found that among 1,497 fully vaccinated healthcare workers, 39 had documented SARS-CoV-2 infections. Most were mild or asymptomatic, but some did have symptoms persist 6 or more weeks.[71,72]
- A letter in the *New England Journal of Medicine* attributed the increase in breakthrough infections among California healthcare workers to "both the emergence of the Delta variant and waning immunity over time, compounded by the end of masking requirements in California and the resulting greater risk of exposure" for healthcare workers (p. 2). The authors concluded that these results indicate a need for rapid reinstatement of nonpharmaceutical interventions (e.g., wearing masks indoors) and increased vaccination efforts.[73]

Studies About SARS-CoV-2 Vaccines

Impact of Vaccines: Subpopulations

- **Older Adults:** In the US, vaccines are effective and there has been a decrease in COVID-19 cases, emergency department visits, hospital admissions, and deaths among older adults, which are the age group with the highest vaccination rates. The elderly population needs to be closely monitored after vaccination and may require earlier revaccination and/or increased vaccine dose.[74-76]
- **Pregnant Women:** Preliminary findings of vaccine safety (for mRNA vaccines) for pregnant persons did not show any obvious safety signals to pregnancy or neonatal outcomes, but continued monitoring is recommended.[77-80]
- **Rural:** Residents of rural communities continue to report lower rates of vaccination compared to urban and suburban areas.[16, 81]
- **Immunocompromised:** Immunocompromised persons (including transplant recipients, people living with HIV infection, and advanced chronic liver disease patients) are more vulnerable to infections and are at high risk of mortality if complicated with COVID-19 infections.[66, 82]
- [New] **Unhoused Population:** In a recent qualitative study, participants found it acceptable to undergo COVID-19 testing in unsheltered settings when the testing was incentivized and supported by community health outreach workers. Most participants expressed willingness to be vaccinated, citing a desire to return to routine life and civic responsibility. Those who expressed hesitancy cited a desire to see trial data, concerns that vaccines included infectious materials, and mistrust of the government.[83]

Studies About SARS-CoV-2 Vaccines

Health Communication and Misinformation

- Scientists have called for efforts to address miscommunication and misinformation on COVID-19 vaccines and restore trust in health authorities.[84-86] Vaccine acceptance will be impeded by misinformation and poor public health communication strategies.[86-88]
- [New] The Lancet Commission on Vaccine Refusal, Acceptance, and Demand in the U.S. recently published recommendations on promoting vaccine acceptance, including behavioral interventions and addressing sociodemographic inequities. Examples included vaccine reminders, offering onsite vaccinations, and vaccine mandates.[89]
- A rapid expert consultation recommended emphasizing support for vaccines, leveraging endorsements, focusing on hesitant individuals, and engaging communities to increase confidence in vaccines.[90]

Reaching High-risk Populations

- Equitable access to COVID-19 vaccines among racial/ethnic minorities is a key concern,[91] as Hispanics and Blacks are less likely to have had at least one vaccine dose compared to Whites and Asians.[92]
- Researchers have identified that COVID-19 continues to disproportionally impact the Black community, further worsening health disparities already present due to racism and its effects on social and economic factors.[52,93-97] Efforts also need to be made to improve access among persons in low socioeconomic (SES) areas and persons with disabilities.[98, 99]

What Research is Still Needed About SARS-CoV-2 Vaccines? [2,11,100]

- How long immunity lasts for different vaccines, including boosters
- How well the vaccines keep people from spreading SARS-CoV-2 to others, even without symptoms
- How well different vaccines will protect against future SARS-CoV-2 variants
- How well vaccines protect people with weakened immune systems and other sub-populations (elderly, pregnant women, children/adolescents)

Key CDC Resources About SARS-CoV-2 Vaccines

- CDC website - Vaccines for COVID-19
- COVID-19 Community, Work, & School Toolkit
- Interim Public Health Recommendations for Fully Vaccinated People
- Key Things to Know About COVID-19 Vaccines
- COVID-19 Vaccinations in the United States

Studies About SARS-CoV-2 Variants of Concern (VOC)

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Studies About SARS-CoV-2 Variants of Concern

Spread, Transmissibility, and Infectivity

- Studies have shown that the B.1.617.2 SARS-CoV-2 variant is more transmissible than the early strain before major mutations (aka the "wild-type" SARS-CoV-2) in children and adults.[101-104]
  - A global analysis of the spread of SARS-CoV-2 variants found that the B.1.617.2 variant had an estimated transmissibility increase of 97%.[101]
  - A study in a large healthcare setting found that from March-July 2021, the weekly percentage of infections attributed to the B.1.617.2 variant quickly increased to 95%, with infection being more common in younger people (aged 18-44 years) and among non-Hispanic Black people.[105]

Current CDC Variants of Concern in the US (as of 14 December 2021)[12]

Variant	WHO Label	First Detected	Other Names
B.1.617.2	Delta	India	20A/S:478K
B.1.1.529 [New]	Omicron	South Africa	21K

[New] **Note: CDC designated Omicron as a VOC on 30 Nov 2021. Due to the recent emergence of this VOC, no scientific literature in this briefing addresses Omicron specifically.** [14]

Studies About SARS-CoV-2 Variants of Concern

Spread, Transmissibility, and Infectivity (Cont.)

- Research suggests that certain mutations present in VOCs are linked with increased transmissibility and infectivity.[106-110]
- [New] Several studies have found that the B.1.617.2 variant has higher secondary attack rates compared to other SARS-CoV-2 variants.
  - A report of an outbreak of the B.1.617.2 variant outbreak in a gymnastics facility found that the variant had a higher secondary attack rate (spread of disease within an infected person's family or other group) compared to the other SARS-CoV-2 lineages. The overall attack rate was 20% in the facility and 53% in households.[111]
  - [New] Findings from studies conducted in Singapore and England showed that the B.1.617.2 variant was associated with increased household transmission compared to other variants.[112,113]

Studies About SARS-CoV-2 Variants of Concern

Outcomes Severity for VOCs (compared to other lineages of SARS-CoV-2)

- Studies have linked B.1.617.2 variant to higher hospitalization rates than B.1.1.7 (Alpha).[114-116]
  - An examination of weekly COVID-19-related hospitalization rates among children and adolescents found that rates were 5 times higher during late June to mid-August 2021, coinciding with the predominance of the B.1.617.2 variant. Hospitalization rates were 10 times higher for unvaccinated adolescents than for vaccinated adolescents.[116]
  - A study examined trends in severe outcomes before (January-June 2021) and during (July-August 2021) the B.1.617.2 variant predominance. Results showed that there were no significant increases in the proportion of people hospitalized with severe outcomes. However, younger, unvaccinated adults (aged 18-29 years) accounted for a larger proportion of those hospitalized.[117]
- A recent study in Mesa County, Colorado where the B.1.617.2 variant increased over a 3-month period to become the predominant variant in that county found that incidence, ICU admission, case fatality ratios, and breakthrough infections were significantly higher compared to other counties.[102]

Studies About SARS-CoV-2 Variants of Concern

Outcomes Severity for VOCs (compared to other lineages of SARS-CoV-2) (Cont.)

- [New] Research indicates that pregnant women are at an elevated risk for severe COVID-19 illness and those with COVID-19 have a higher risk for negative perinatal outcomes.
  - A study found that the proportion of pregnant women with COVID-19 with severe or critical illness increased as the B.1.617.2 variant become predominant.[118]
  - [New] A recent study found that during March-September 2021, women with COVID-19 had a higher risk for stillbirth compared to women without COVID-19. The rates of stillbirths among women with COVID-19 were higher during the period when the B.1.617.2 variant was predominant (2.70%) compared to the period before it was predominant (0.98%).[119]
- Specific mutations that have been identified in SARS-CoV-2 variants have been associated with varying severity of COVID-19 illness.[120-122]

Studies About SARS-CoV-2 Variants of Concern

Impact of Vaccines on the Variants

- Several studies have found the Pfizer-BioNTech and Moderna vaccines to be effective against infection with the B.1.617.2 variant and severe outcomes.
  - A study of a B.1.617.2 variant outbreak in a prison found the effectiveness of the Moderna vaccine to be 56.6% against infection and 84.2% against symptomatic infection.[123]
  - A study of the effectiveness of the Pfizer-BioNTech vaccine against the B.1.617.2 variant among adolescents aged 12-18 years found it to be 90% effective against infection and 93% effective against symptomatic infection.[124]
  - The effectiveness of the Pfizer-BioNTech vaccine against death by the B.1.617.2 variant in Scotland was 95% among persons aged 40-59 years and 87% among those aged 60 years or older. No deaths occurred among fully vaccinated persons aged 18-39 years.[125]
  - [New] A study of the effectiveness of the Pfizer-BioNTech and Moderna vaccines in Qatar showed that although the vaccines were modestly effective in preventing infection with the B.1.617.2 variant (55.5% effectiveness for either vaccine ≥14 days after the 2^{nd} dose), the vaccines were highly effective in preventing severe, critical, or fatal disease (93.6%).[126]

Studies About SARS-CoV-2 Variants of Concern

Impact of Vaccines on the Variants (Cont.)

- Although the Pfizer-BioNTech and Moderna vaccines continue to be effective, studies indicate that their effectiveness reduced as the B.1.617.2 variant became more predominant.[127,128]
  - Studies have found that the B.1.617.2 variant exhibits some resistance to vaccine-elicited antibodies.[129-132]
- A study assessing the impact of variants (including B.1.617.2, B.1.1.7 [Alpha], B.1.351 [Beta], and P.1 [Gamma]) on antibodies elicited by vaccine mRNA-1273 (i.e., Moderna) showed that all individuals had responses to all variants on Day 43, the peak of response to the 2nd vaccine dose. Antibodies persisted 6 months after the 2nd dose (at lower levels), supporting studies on the potential need for booster vaccinations.[133]
- Interim analysis from an ongoing trial showed that administering a booster dose of the Moderna vaccine to healthy adults was linked with increased neutralizing antibodies (NAbs) against the wild-type virus and variants (B.1.617.2, B.1.351, and P.1).[134]
- [New] A study examining the effectiveness of the Pfizer-BioNTech in reducing viral loads of B.1.617.2 variant breakthrough infections (BTIs) found that fully vaccinated individuals had lower viral loads than unvaccinated persons. However, this effect declined and ultimately vanished at 6 months or longer after vaccination.[135]
  - However, findings indicated that administering a booster dose restored the effectiveness of the Pfizer-BioNTech vaccine in reducing viral loads.[135]

Studies About SARS-CoV-2 Variants of Concern

Continued Use of Established Mitigation Strategies

- Studies show it is critical to continue existing public health strategies (e.g., physical distancing, hand hygiene, mask wearing, people quarantining after exposure) to reduce the transmission of SARS-CoV-2 variants particularly among unvaccinated persons who have a higher transmission risk.[136-138]
- Recent studies on the rapid spread and infectivity of the B.1.617.2 variant highlight the importance of maintaining prevention strategies such as wearing masks indoors regardless of individuals' vaccination status.[108,139]
  - Recent studies examining mask requirements in K-12 school settings have linked requiring prevention strategies to lower COVID-19 pediatric case rates.[140,141]
  - One study of breakthrough infections with the B.1.617.2 variant among vaccinated healthcare workers found these infections were driven by social gatherings and household exposures where people were largely unmasked. The rate of secondary infections was very low (0.75%) with most instances occurring when HCWs were not wearing masks (e.g., when eating).[142]

What Research is Still Needed About SARS-CoV-2 Variants of Concern? [2,13]

- How transmissible these variants of SARS-CoV-2 are for certain demographics (e.g., older adults)
- The likelihood of reinfection due to SARS-CoV-2 variants of concern
- How the infectious dose (amount of virus needed for infection) differs between variants of concern and the wild-type lineage
- How these variants of concern may affect existing therapies, such as vaccines

Key CDC Resources About SARS-CoV-2 Variants

- Variants of the Virus
- What You Need to Know About Variants
- Variant Proportions (US COVID-19 Cases Caused by Variants)
- Understanding Variants
- Delta Variant: What We Know About the Science
- Omicron Variant: What You Need to Know

Studies About the Effects of Ventilation on SARS-CoV-2

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Studies About the Effects of Ventilation on SARS-CoV-2

General Findings

- Excess CO_2 concentration has been shown to trend with relative risk of infection, but some researchers have warned against using CO_2 as a proxy for infection risk.[143-148] There are relatively inexpensive indoor air quality monitoring systems that can be used to monitor CO_2 levels in different rooms of a building.[149]
  - Monitors and smoke visualization can also be used to visualize places where stale air may accumulate (e.g., around privacy screens or large items).[150]
- Theoretically, many factors influence whether ventilation is successful in the elimination or decrease of SARS-CoV-2 particles in the air, including activities occurring in the space, occupancy rates, viral load, and various ventilation parameters.[151-153]
- Air purification or ventilation alone is not enough to decrease virus particles to below guideline levels, but ventilation, purification, and implementation of other mitigation measures (mask wearing, occupancy restrictions, surface cleaning) can reduce risk of infection drastically.[154-156]
- Researchers have proposed developing a ventilation strategy based on a high-rise building's occupancy. Adjusting air change rates as occupancy increases or decreases may help with energy efficiency and reduce electricity costs.[157]

Studies About the Effects of Ventilation on SARS-CoV-2

General Findings (Cont.)

- A study found that ventilation changes were effective at reducing mean transmission risk in classrooms by 25%, while increasing social distancing from 1.5 to 3 meters decreased transmission risk by 65%.[158]
- Researchers created an app to determine exposure times and occupancy levels based on ventilation, room specifications, and other parameters.[159]
- Modeling research has shown that the probability of infection may be influenced more by how close a person is to someone carrying SARS-CoV-2 than by the amount of fresh air in a space.[160-162]
- One study looked at impacts of various mitigation measures on long-range and short-range transmission risk. Increasing ventilation resulted in a 17-fold decrease in risk at long range, but only a 6-fold decrease in risk at close range. Additionally, the benefit of maintaining a 2m or 1m distance was dependent on air turbulence and ventilation rate in the space.[163]
- Researchers in Slovenia conducted a 125-day study of indoor air quality in kindergarten classrooms. They emphasized the need for clear, standard procedures regarding ventilation and the need to educate staff on the importance of ventilation for improving indoor air quality and mitigating virus transmission.[164]

Studies About the Effects of Ventilation on SARS-CoV-2

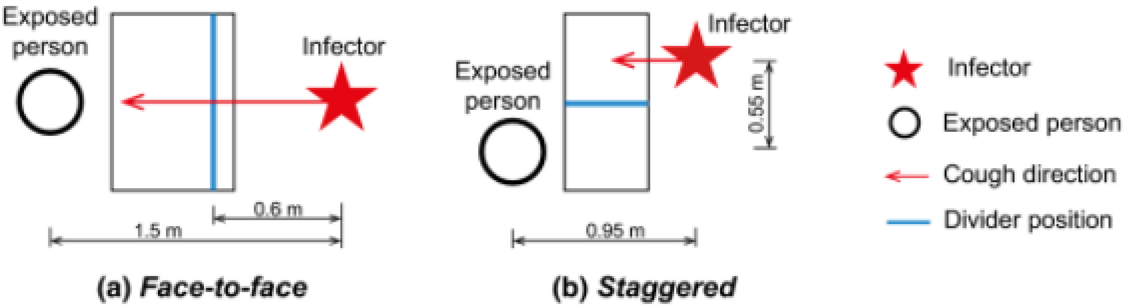
General Findings (Cont.)

- A study about the effects of placing dividers between patrons in public spaces (e.g., restaurants) showed limited impact on controlling airborne transmission and that dividers may cause aerosols to gather. However, the researchers still recommended use of dividers to block direct contact and spread of large droplets between patrons. The researchers also recommended that transmission risk could be reduced by cleaning the spaces created by dividers and leaving them empty (at least 6 minutes) between patrons, as well as using other tactics like increases in air change rates, social distancing, and shortening usages of the spaces.[165]
  - Another group of researchers studying dividers' impact on infection risk found that a partition can effectively block expiratory particles at breathing height (in the context of diners seated at tables). However, this partition can also trap infectious particles if not enough time is allowed between diners. The researchers noted that it takes 11 minutes for the expiratory CO_2 trapped by the divider to decay to the background concentration.[166]
  - In a classroom study looking at aerosol dispersion from one source, three-sided clear dividers placed around desks resulted in reduced aerosol concentrations at monitors placed on desks. The authors noted that if desks are placed 1.5 meters or less apart, dividers may help to reduce exposure and risk of infection.[167,168]
  - In another classroom study, researchers found that the amount of suspended droplets decreases as ventilation velocity increases. Generally, seats in the classroom with partitions were exposed to fewer suspended droplets than seats in the classroom without partitions.[168]
  - Another study found that a barrier height of at least 60 cm above a desk surface is needed to prevent virus transmission in spaces that are well-ventilated.[169]

Studies About the Effects of Ventilation on SARS-CoV-2

General Findings (Cont.)

- [New] A study looking at optimal divider placement found that:
  - A face-to-face layout (figure [a] below) with a divider separation reduced 99% of potential exposure in the breathing zone of the exposed person. However, viral particles may be reflected off the divider and expose people standing next to the infector.[170]
  - Dividers placed in a staggered layout (figure [b] below) can reduce viral particles in the exposed person's breathing zone by 60%. The authors concluded that the staggered layout reduced exposure the best because the face-to-face layout included risk of exposing people standing next to the infector.[170]



Source: Li W, Chong A, Lasternas B, Peck TG, Tham KW. Quantifying the effectiveness of desk dividers in reducing droplet and airborne virus transmission. Indoor air. 2021 Oct 27.

Studies About the Effects of Ventilation on SARS-CoV-2

General Findings (Cont.)

- A dedicated outdoor air system (DOAS) is used in many health care settings to provide high rates of ventilation. This unit pumps 100% outdoor air into a space and is used in conjunction with an air-handling unit to heat and cool the air. DOAS are generally placed on rooftops, but new versions of the technology are smaller and more affordable.[171]
- [New] Researchers in Portugal sought to estimate the percentages of aerosol infection risk reduction of COVID-19 using a modeling approach. In schools, they found that completely opened windows lowered risk of infection by 64% when compared to closed windows. In mechanically ventilated spaces, risk of infection dropped significantly when air flow rates were doubled. Lastly, risk of infection was reduced by 72% when HEPA filters were used in schools.[172]
  - [New] Another study found that air filtration is the single most effective ventilation strategy to reduce risk of SARS-CoV-2 transmission in schools.[173]
- [New] In one study, researchers examined the effects of a variety of HVAC parameters on SARS-CoV-2 transmission rates. These mitigation strategies had the greatest effect at high particle emission rates. When the number of particles emitted was low, the effect of ventilation mitigation strategies was negligible. Overall, the scientists confirmed that HVAC systems alone cannot reduce the transmission risk to zero.[174]
  - [New] Conversely, several studies have documented evidence of SARS-CoV-2 transmission via inadequate ventilation, indicating that there is a risk that COVID-19 could be spread via ventilation systems.[175,176]

Studies About the Effects of Ventilation on SARS-CoV-2

Air Purification

- Various studies have found that air purifiers are effective in decreasing the concentrations of aerosols in a space and that purifiers are most effective if placed close to the emitter.[177-181]
- The most effective air purifiers to use against SARS-CoV-2 are those that use HEPA filters, ionizers, or ultraviolet germicidal irradiation (UVGI).[182]
- CO_2 monitors can be used to gauge the degree of ventilation in a space.[143-147] However, since air purifiers are intended to filter the air of pathogens and CO_2 monitors do not measure the presence of pathogens, the effect of air purifiers on pathogens (e.g., SARS-CoV-2) will not be captured by CO_2 monitors.
- Researchers designed and tested a low-cost air purification device using a box fan, MERV-13 filter, and a cardboard support.[183]
  - Researchers tested this purification device at approximately two air changes per hour, which is typical of a classroom built before 1989. The device reduced the risk of airborne transmission in a classroom setting, lowering the percentage of suspended aerosols in the room to as low as 1% when placed next to the ventilation source.[183]

Studies About the Effects of Ventilation on SARS-CoV-2

Air Purification (Cont.)

- Filters should fit snugly in their housings to mitigate filter bypass and should be replaced according to the instructions on the filter.[184]
- PPE should be worn when replacing air filters to reduce exposure to viral particles.[177]
- There is some evidence that the noise from mobile air purifiers (MAP) may lead to louder speech, which could result in the release of more virus particles. Researchers found that a MAP only successfully removed viral particles in a classroom under very specific circumstances (MAP close to emitter, high volume flow).[185,186]
- Air purifiers have emerged that use a process called photocatalysis. These purifiers do not use filters, but instead use UV light and a semiconductor to destroy viral particles. Research on this type of purifier is still emerging, but the advantage of purifiers that use photocatalysis is that they destroy viral particles rather than just trapping them.[187]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems

- There is a risk that HVAC systems could worsen spread of COVID-19 if not designed or modified to maximize circulation of virus-free air into a space.[179,188]
- Displacement ventilation systems, or those "designed to vertically stratify indoor air by temperature (warm air at the top of the room, colder air at the bottom) and remove warmer air" were found most likely to reduce risk of SARS-CoV-2 transmission via HVAC.[165,189,190]
- Conversely, other studies found that unstable or neutrally stratified air (warm air at the bottom of the room, or no discriminate layers of warm or cold air) reduced the risk of infectious aerosols remaining at one height in the breathing environment.[146]
  - Researchers found that thermally stratified rooms (i.e., separation of warm air toward the top of a room and cooler air toward the bottom) showed higher infection risk than well-mixed rooms where social distancing of greater than 2 meters had taken place. The authors noted that the "infection risk show[ed] multiple peaks" in rooms thermally stratified using displacement ventilation, under-floor air distribution, and displacement nature ventilation (p. 7).[191]
  - Additionally, researchers have found that for rooms that have floor-level heating and ceiling-level cooling, displacement or mixed ventilation systems may be best suited for reducing SARS-CoV-2-laden aerosols. In rooms with ceiling-level heating and floor-level cooling, localized ventilation systems are recommended (e.g., personalized ventilation or push-and-pull ventilation).[146]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems (Cont.)

- Ventilation at only one point in a room (e.g., portable AC unit, both inlet and outlet in the ceiling) is unlikely to efficiently remove virus particles in the absence of other precautions (e.g., masks, social distancing, etc.).[150,192,193]
- Inadequate or inappropriately positioned ventilation may lead to virus hotspots or increased surface deposition.[189,192]
- Incorporation of UV-C light into duct systems was shown to inactivate 99.98% of virus in the air that passed through the duct. In-duct UV-C can also be combined with HEPA filtration.[189,194]
  - Upper room ultraviolet germicidal irradiation (UVGI) can also be used to disinfect warm air as it rises toward the ceiling. UVGI can be used with displacement ventilation or ceiling fans to continually mix and disinfect the air in the room.[188,189]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems (Cont.)

- Increasing air change rates can lead to higher energy costs. These costs can be offset by ‘smart’ systems, which only ventilate rooms when they are occupied, and also by natural ventilation.[169,171,177-197]
  - While many researchers have recommended increasing air change rates to mitigate spread of COVID-19, some researchers caution that an increase in air change rate may lead to more rapid spread of infectious particles to connecting rooms or may less effectively remove particles in certain situations.[193,194]
- Air diffusers and return vents located in such a way that circulated air is contained in one physical space (also called localized flow regimes) may mitigate the spread of contaminated air.[189]
- Outdoor air dampers can be opened beyond the minimum settings to reduce indoor air recirculation (weather and temperature permitting).[184]
- It may be beneficial to run HVAC at maximum outdoor airflow for a period of time (e.g., 2 hours) before a space is occupied.[184]

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems (Cont.)

- Increasing the fraction of outdoor air and using a MERV-13 filter (rather than a MERV-8 filter) were found to be more likely to reduce spread of SARS-CoV-2 between adjoining rooms.[194]
- Experts recommended that exhaust fans in restrooms should operate at all times. They also noted that windows in restrooms with exhaust fans should not be opened, as exhausted air may reenter.[198]
- HVAC systems tend not to be built for airborne infection control and may only operate at a small fraction of the room air change rate needed to stop virus spread.[161]
  - Air may need to be circulated more frequently in high traffic areas (e.g., communal space and bathrooms).[162]

Studies About the Effects of Ventilation on SARS-CoV-2

Historic Buildings & Natural Ventilation

- There is divergent evidence regarding whether natural ventilation alone can decrease CO_2 amounts to below air quality recommendations.[144,147,199]
- In a study of New York City school buildings, transmission was found to be lower in older buildings compared to newer buildings, likely due to "greater outdoor airflow" (i.e., drafts). Transmission rate was also found to be lower in schools with mechanical ventilation (when compared to natural ventilation).[200]
- Findings on the impact of wind speed and direction on ventilation rates and transmission are contradictory.[143,199]
- Research remains inconclusive on whether cross-ventilation or adjacent window ventilation results in better airflow.[153,201]
- Fans can be placed in open windows to increase the effectiveness of natural ventilation. Air should exhaust to the outdoors.[159]

Studies About the Effects of Ventilation on SARS-CoV-2

Effects of Temperature & Humidity

- Because ventilation with outdoor air is more difficult in colder months, researchers have estimated that airborne infection risk is double that of summer months.[145,182,188]
  - Windows need to be opened less in winter to achieve the same ventilation rates as open windows in summer due to temperature differences between outdoor and indoor air and wind speed.[150]
  - During these months, monitoring indoor carbon dioxide as a proxy for ventilation is recommended and should not exceed 1000 ppm.[202]
  - In the absence of carbon dioxide monitoring, attention should be paid to areas with stagnant air.[195]
- Researchers recommended further studies on humidification of air, which could increase the speed at which SARS-CoV-2 particles drop to the ground or surfaces.[203]
- The taller a building is, the more prone it is to stack effect, especially in colder climates. Stack effect occurs when pressure differences between floors cause air to stagnate on upper floors. This effect may also cause a reversal of airflow and contaminants may spread to other areas of the building.[204]
- A study analyzing the effects of ventilation rate and relative humidity on airborne levels of SARS-CoV-2 found that increasing the air change rate decreased infection risk more than increasing the humidity in a space.[205]
  - Further, a study analyzing the impact of humidification on SARS-CoV-2 transmission risk found that humidifying a space to 40-60% relative humidity is unlikely to significantly reduce transmission risk.[205]

What Research is Still Needed About the Impact of Ventilation on SARS-CoV-2?

- Consensus on how best to configure, upgrade, or design ventilation systems to mitigate the spread of SARS-CoV-2
  - What role thermal stratification plays in infection risk
- Whether variants that are more transmissible can be mitigated using the same ventilation methods that are effective for other strains.
- How results may differ if ventilation-related studies used SARS-CoV-2 instead of surrogate substances (e.g., carbon dioxide).
- How to best to utilize UVGI (upper room and/or in-duct) to reduce virus particles in a space.
- What impact plexiglass barriers and other dividers have on rates of spread and mitigation of SARS-CoV-2.[206]
- Regarding natural ventilation, understanding whether opening adjacent windows or windows across from each other is more effective at ventilating a space.
- The effect of wind speed and direction on natural ventilation and, consequently, transmission risk.
- Best practices for balancing energy efficiency with increased ventilation rates (and increased energy use) to mitigate transmission risk.
- The costs and benefits of all ventilation methods that could be used to reduce infection risk.[207]

Key CDC Resources About Ventilation to Mitigate SARS-CoV-2

- Ventilation in Buildings
- COVID-19 Resources for Workplaces & Businesses
- Improving Ventilation in Your Home
- Ventilation and Coronavirus (COVID-19) (Environmental Protection Agency resource)

HOW THIS BRIEFING WAS CREATED (METHODOLOGY)

REALM PROJECT

OCLC INSTITUTE of Museum and Library SERVICES BATTELLE

How This Briefing Was Created

- In January 2021, REALM stakeholders developed Phase 3 research questions. An additional question related to ventilation was added in May 2021. In October 2021, the variants section was refocused on current variants of concern in the US.
- Battelle developed search strings that included variations of the term “SARS-CoV-2” and novel terms for vaccine and variants using Boolean operators. The Boolean operator “AND” was used to separate SARS-CoV-2 and research question terms, while different variations of the virus name and keywords related to the research question were grouped by category using parentheses and the Boolean operator “OR” (e.g., ["SARS-CoV-2" OR "2019-nCoV" OR "COVID-19"] AND [vaccine OR variant]). Search strings are included in the appendix.
- Battelle developed research question keywords using ad hoc test searches and comparison against known relevant articles. Databases were selected (Scopus, SciTech, Web of Science, and MEDLINE) to provide comprehensive search capacity and inclusion of smaller databases.
- The initial search string included a time criterion to capture articles published in January 2021 and after. Subsequent searches were executed on weekly durations. Note: when the ventilation research question was added in May 2021, articles were searched from 01 January 2021 forward to cover the same time period as the other research questions.

How This Briefing Was Created (cont.)

- Battelle staff reviewed the titles and abstracts of search results to select those most relevant to the research questions for additional examination.
- The DHS Master Question List for COVID-19 and CDC Morbidity and Mortality Weekly Reports (MMWR) were reviewed to verify the completeness of the search results (i.e., to double-check that relevant articles were not missed by the search strings).
- Battelle staff analyzed the relevant articles to identify key subtopics and prioritize high-value articles. Summaries of the articles, organized by subtopic, were presented to OCLC, IMLS, and REALM working groups for feedback.
- Battelle summarized the results for this briefing, which is a cumulative report that builds on prior briefings by adding new relevant research findings published 02 November to 29 November 2021. Additional information was also added from the CDC to provide context on the key topics, and sections have been updated over time to remove information that is no longer timely.

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APPENDIX: SEARCH STRINGS

REALM PROJECT

Database	Strategy: Vaccines and Variants of SARS-CoV-2
Scopus	((TITLE-ABS (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TITLE-ABS (spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND TITLE-ABS (variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain)) AND NOT TITLE-ABS (receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv))
SciTech	(ti,ab(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND ti,ab(spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND ti,ab(variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain)) NOT ti,ab(receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv)
Web of Science	TS=(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TS=(spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND TS=(variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain) NOT TS=(receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv)
MEDLINE	(TI (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TI (spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND TI (variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain) NOT TI (receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv)) OR (AB (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND AB (spread* OR transmi* OR infect* OR reinfect* OR virulence OR neutraliz* OR sever* OR evad* OR airborne OR aerosol* OR occupation* OR infectiv* OR mortality OR morbidity OR death*) AND AB (variant OR vaccine OR mutat* OR mutant* OR lineage OR immun* OR strain) NOT AB (receptor OR inflamm* OR peptide* OR nanomaterial OR ace2 OR polymerase OR "IgA" OR patient* OR assay* OR ligand* OR protease OR hiv))

Database	Strategy: Effects of Ventilation on Spread of SARS-CoV-2
Scopus	(TITLE-ABS (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TITLE-ABS (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) AND TITLE-ABS (indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) AND NOT TITLE-ABS (pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) AND (LIMIT-TO (PUBYEAR , 2021))
SciTech	(TS=(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND TS=(spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) AND TS=(indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) NOT TS=(pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) AND PUB YEAR= 2021
Web of Science	(TI (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") OR AB (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV")) AND (TI (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) OR AB (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*)) AND (TI (indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa) OR AB (indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) NOT (TI (pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) OR AB (pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase)) Date of Publication: 20210101-20211231
MEDLINE	(ti,ab(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") AND ti,ab(spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc*) AND ti,ab(indoor OR office OR "climate controlled" OR ambient OR air OR airborne OR aerosol* OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa)) NOT ti,ab(pollution OR particulate* OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR patient OR phenotype OR clinical OR polymerase) Date: After January 01 2021

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