# Emerging Evidence on COVID-19

# COVID-19 Summary of Heating, Ventilation, Air Conditioning (HVAC) Systems and Transmission of SARS-CoV-2

## Introduction

*What is the impact of Heating, Ventilation, Air Conditioning (HVAC) systems on SARS-CoV-2 virus transmission?*

This evidence brief summarizes relevant literature up to August 13, 2020 on the potential role of HVAC systems in the transmission of SARS-CoV-2. Evidence from other related respiratory infections (i.e. SARS, MERS-CoV) was also identified to improve our understanding of the possible role of HVAC systems in transmission of similar viruses.

## Key Points

- SARS-CoV-2 RNA contamination in air samples and HVAC system surfaces (e.g. air grates and filters) from healthcare settings indicate it may be possible for SARS-CoV-2 to spread through the HVAC system (Table 1). The viability of isolated viral RNA has not been confirmed by cell culture in the majority of studies, with the exception of two studies that collected viable virus from air samples in COVID-19 patients' rooms.
  - Lednicky and colleagues demonstrate viable SARS-CoV-2 can be found in air 2 to 4.8 meters away from patients in hospital care settings, using virus culture (RT-qPCR) (Lednicky et al., 2020). Moreover, the authors suggest virus particles becoming inactivated during sample collection to be the reason for studies failing to culture viable SARS-CoV-2 in air samples.
  - Air samples from a hospital setting treating SARS-CoV-2 patients were contaminated with viral RNA. Minor indications of cytopathic effects and viral replication were observed in an air and surface sample (Santarpia et al., 2020).
- A single study reports on the presence of SARS-CoV-2 RNA downstream of air filters in a hospital ventilation system, however the viability of the isolated virus was not evaluated (Table 1). As such, the potential for SARS-CoV-2 infection from air circulated through a ventilation system remains unestablished.
- A small number of SARS-CoV-2 clusters has been attributed to air conditioning units and air recirculation (Table 2) at a dine-in restaurant (Lu et al., 2020), bus ride to a worship event, and a professional workshop (Shen et al., 2020). Strong air jets created by air conditioning units and the recirculation of indoor air are considered likely modes transmitting infectious respiratory particles

from the index case to other susceptible individuals nearby (Yuguo Li et al., 2020). Other investigations into SARS-CoV-2 outbreak in a cruise ship have failed to implicate the HVAC system in infection transmission (Almilaji & Thomas, 2020; Xu et al., 2020).

- Transmission of other coronavirus infections (i.e. MERS and SARS) predating SARS-CoV-2 point to an association between poor ventilation (i.e. insufficient movement and clearance of contaminated indoor air) and infection transmission, this association likely extends to SARS-CoV-2 (Table 4).
- Expert statements and guidance documents advocate for HVAC testing and certification to ensure properly functioning systems to minimize air contaminants in indoor settings based on local standards.
- Commentaries and reviews that consider the body of evidence on the topic, and mathematical models, consistently report that increasing the flow of outside fresh air into built environments (e.g. open windows) and reducing occupancy within enclosed indoor settings, where feasible and appropriate, to be simple strategies that can mitigate SARS-CoV-2 transmission in indoor settings (Dai & Zhao, 2020; Dietz et al., 2020; Morawska & Cao, 2020).

## Overview of the Evidence

Various investigations have aimed to evaluate the evidence connecting HVAC systems and indoor air to infection transmission, both before and following the emergence of COVID-19. The variability of studies in their design, experimental settings (healthcare vs. non healthcare), examined viral pathogens, and HVAC systems do not allow direct comparison of the literature.

Nine surveys of environmental contamination in hospitals with COVID-19 patients provide a snapshot of virus laden surfaces (Table 1). These studies are of moderate risk of bias as they are point in time observational surveys that confirm the presence of viral RNA, but many do not confirm the infectiousness of identified viral particles. Four outbreaks where HVAC systems were investigated as a source of infection transmission have been described in various retrospective epidemiological investigations (Table 2). These epidemiological investigations are at high risk of bias, as demonstrated by the conflicting reports about the Diamond Princess cruise ship where different analytical approaches and assumptions led to different conclusions. Mathematical models and computer simulations were parameterized using observational data from a small number of outbreaks to explore scenarios of how HVAC systems can impact SARS-CoV-2, MERS, and SARS transmission (Table 2 and Table 4). Caution should be exercised when interpreting these findings, as the extent to which the results can be generalized is variable.

There are several knowledge gaps in the current COVID-19 literature. The available evidence has not directly established infectious SARS-CoV-2 particles can travel through an HVAC system or system generated air flow to cause infection when reintroduced to a susceptible population of individuals. Evidence on the optimal number of air changes per hour required in non-healthcare settings, ideal ventilation system configurations, and the role of HEPA filters in mitigating SARS-CoV-2 transmission is limited.

# CONTENTS



## LITERATURE ON INFECTION TRANSMISSION AND HVAC SYSTEMS

There are no studies that specifically quantify SARS-CoV-2 transmission risk due to HVAC systems or indoor ventilation. Nine studies conducting environmental sampling identified SARS-CoV-2 viral RNA in air samples and on surfaces of HVAC system components (e.g. pre and post air re-circulation filters, air dampers, air grates) in healthcare settings treating COVID-19 cases; virus viability and infectiousness was not established in the majority of studies (Table 1). Thus, dispersion of viable SARS-CoV-2 by a HVAC system has not been demonstrated.

A single cluster of COVID-19 cases from three unrelated families are reported to be associated with air circulation and uni-directional air streams generated by a ductless air conditioning unit in a Chinese restaurant (Lu et al., 2020). In this cluster, the index case from Family A dined upwind of Families B and C, who did not have any other connections or exposures to Family A. Staff and other patrons were not affected. Air re-circulation in enclosed environments linked to air conditioning units, indoor ventilation and fans are reported to have played a role in two unrelated SARS-CoV-2 outbreaks, from a religious worship event and a professional workshop(Shen et al., 2020). Moreover, the HVAC system on-board the Diamond Princess cruise ship that had a large COVID-19 outbreak was also investigated for evidence of its contribution to SARS-CoV-2 spread. One study took into account the lock-down, quarantine period, and incubation period and provides evidence that the quarantine of passengers in cabins stopped transmission on board the ship and no transmission could be attributed to ventilation (Xu et al., 2020). A second study that analysed the same data suggests transmission via circulating air may have occurred, but failed to account for the incubation period (Almilaji & Thomas, 2020).

Investigations of clusters of coronaviruses that predate the emergence of COVID-19 have been linked to poor indoor ventilation and HVAC systems being non-functional (Haselbach et al., 2009; Y Li, Huang, Yu, Wong, & Qian, 2005; Satheesan, Mui, & Wong, 2020; Wong et al., 2004). Multiple investigations into a MERS-CoV cluster within a patient isolation unit attribute high air flow near an infected patient, imbalanced supply and exhaust airflow rates, and a malfunctioning exhaust and air supply to infection spread to healthcare workers (Y Li et al., 2005; Wong et al., 2004). A US study of acute respiratory infections occurring in several army barracks of different designs attributed the HVAC configurations (i.e. the number of individuals that come in contact with and share recirculated air in an HVAC system) to increased infection rates, however they failed to rule out direct transmission (Haselbach et al., 2009). Although this literature is not specific to SARS-CoV-2, it does provide evidence that poor ventilation and non-functional HVAC systems are associated with respiratory infection transmission in indoor settings.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), a leading US authority on HVAC system design, operation and maintenance, published a position statement on COVID-19, in April 2020. The position statement advocates for properly functioning HVAC systems as these systems are designed to reduce contaminants in indoor air and as a result minimize airborne transmission of pathogens such as SARS-CoV-2. This statement has been adopted by other organizations, including the Center for Disease Control and Prevention, in back to work and business re-opening guidance.

### Table 1: Literature on SARS-CoV-2 contamination of air and air vents in healthcare settings

| Reference | Publication Title | Key Outcomes |
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| **Environmental Surveys** | | |
| (Lednicky et al., 2020) *preprint* | Viable SARS-CoV-2 in the Air of a Hospital Room with COVID-19 Patients. | Air samples were collected from a designated SARS-CoV-2 hospital ward housing infected patients, in Florida, USA. VIV AS and BioSpot air samplers that preserved virus viability were used for sample collection.<br><br>Viable virus was isolated from air samples collected 2-4.8 meters away from infected patients, thus supporting viable SARS-CoV-2 virus dispersion within airborne aerosols in healthcare settings. Genomic sequencing establishes a relationship between viral RNA isolated from air samples and an infected patient occupying the ward.<br><br>Finally, viable virus was only isolated from air samples collected without a HEPA filter cover on inlet tubes, based on cytopathic effects on Vero E6 cells. Isolated virus concentrations in air samples ranged from 2-74 $TCID_{50}$ units/L of air. |
| (Horve et al., 2020) *preprint* | Identification of SARS-CoV-2 RNA in Healthcare Heating, Ventilation, and Air Conditioning Units. | Surfaces of air handling units in a healthcare facility treating COVID-19 patients in Oregon, USA were tested for the presence of viral RNA within HVAC systems. The presence of viral RNA was confirmed by RT-PCR.<br><br>25% of sampled surfaces from multiple air handlers were contaminated with SARS-CoV-2 RNA; positive samples were identified on pre-filters (35%), supply air dampers (20.8%), and final filters (16.67%). Recovered viral gene copies decreased from the pre-filter to final filter surfaces. |

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| | | The supply air dampers and air sampled in this study represent re-circulated air that is mixed with outside air pre and post HVAC filtration. Samples were found to be contaminated with viral RNA, which is concerning. Since no attempt was made to culture the virus, further research is needed to further investigate the implications of this study; typical filtration systems in healthcare settings may not completely eliminate the passage of viral particles. |
| (Cheng et al., 2020) | Air and Environmental Sampling for SARS-CoV-2 Around Hospitalized Patients with Coronavirus Disease 2019 (COVID-19). | Air samples near asymptomatic and symptomatic COVID-19 patients (n=6) with and without surgical masks in an airborne infection isolation room (AIIR), in Hong Kong and China, were tested for SARS-CoV-2 contamination.<br><br>All collected air samples were negative for SARS-CoV-2 RNA. |
| (Chia et al., 2020) | Detection of Air and Surface Contamination by<br>SARS-CoV-2 in Hospital Rooms of Infected Patients. | Environmental surface and air samples from airborne infection isolation rooms (AIIR) housing COVID-19 patients in Singapore were tested for SARS-CoV-2 RNA. Among the contaminated surface samples, the floors followed by air exhaust vents were the most contaminated.<br><br>66% (n=2/3) of the air samples collected from AIIR environments were SARS-CoV-2 RNA positive. The authors suggest the presence of SARS-CoV-2 in the air is likely highest during the first week of illness when respiratory viral load is high.<br><br>The infectiousness of the recovered viral particles were not assessed. |
| (Liu et al., 2020) | Aerodynamic Analysis of SARS-CoV-2 in Two Wuhan Hospitals. | SARS-CoV-2 RNA concentrations in aerosol samples, the size and deposition of airborne SARS-CoV-2 aerosols from Wuhan, China hospital settings was quantified. Sampled environments included patient care, public and staff areas within or near a hospital, and field hospital settings.<br><br>In patient care areas SARS-CoV-2 concentrations from air samples were very low to undetectable, suggesting the negative pressure isolation room and high rate of air exchange was effective. |

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| | | In the field hospital setting, the greatest SARS-CoV-2 suspended aerosols were identified in a temporary patient toilet room (1 $m^2$ area) with low ventilation.<br><br>In public areas low to undetectable SARS-CoV-2 suspended aerosol concentrations were identified for the majority of sampled public areas. However, virus concentrations were detected in two public sites, a department store entrance and an outdoor site near the hospital. Results suggest high traffic flow and crowding may play a role in the presence of SARS-CoV-2 detection in air samples.<br><br>Healthcare worker staff areas had the highest SARS-CoV-2 concentrations and aerosol size distributions. Samples from the field hospital staff personal protective equipment removal and changing rooms demonstrated the greatest virus concentrations and aerosol size distribution. The authors hypothesize the observed high concentrations are due to resuspension of virus containing aerosols from healthcare worker PPE surfaces and apparel.<br><br>The infectiousness of recovered viral particles was not established. |
| (Guo et al., 2020) | Aerosol and Surface Distribution of Severe Acute Respiratory Syndrome Coronavirus 2 in Hospital Wards, Wuhan, China, 2020. | 35% of air samples collected from hospital ICU and general wards in Wuhan, China tested positive for SARS-CoV2 virus particles. Positive samples were identified near air outlets (35.7%), patient rooms (44.4%) and physician offices (12.5%). Virus-laden samples were most often identified downstream from COVID-19 patients.<br><br>In the ICU ward space, patient care and treatment areas were positive for SARS-CoV-2 virus aerosols, and positive samples were identified up to 4 meters from a COVID-19 patient.<br><br>In the general ward's space, areas positive for SARS-CoV-2 were within 2.5 meters upstream of the patient.<br><br>No SARS-CoV-2 virus aerosols were identified in patient corridor areas. |

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| | | The infectiousness of recovered viral particles was not established. |
| (Ong et al., 2020) | Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) From a Symptomatic Patient. | Survey of air samples collected from negative pressure airborne infection isolation rooms (AIIR), containing anterooms and bathrooms, in the dedicated SARS-CoV-2 outbreak center in Singapore, housing three symptomatic confirmed cases of COVID-19.<br><br>Although some environmental samples were found to be SARS-CoV-2 contaminated, no air samples were positive for SARS-CoV-2 virus.<br><br>The infectiousness of recovered viral particles was not established. |
| (Santarpia et al., 2020) *preprint* | Aerosol and Surface Transmission Potential of SARS-CoV-2. | Air and surface samples from isolation spaces housing COVID-19 cases at the University of Nebraska, United States were collected and tested for SARS-CoV-2 viral RNA by RT-PCR.<br><br>63.2% of air samples from patient isolation areas were positive for viral RNA, particularly under the patient's bed and window ledges at the edge of the room. Based on airflow modelling, the authors suggest turbulent eddies (i.e. swirling of a fluid and the reverse current created when the fluid is in a turbulent flow) that form under the patient's bed, and dominate airflow carrying respiratory/viral particles away from the patient toward the edges of the rooms led to the observed contamination. 58.3% of air samples collected in hallways outside of patient isolation areas also contained the virus.<br><br>The surface of an air grate was found to be contaminated with SARS-CoV-2; the highest viral load observed was recovered from this study surface (1.75 copies/μL).<br><br>The study findings suggest viral aerosol particles can be produced by infected individuals even during the absence of |

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| | | cough, with the virus travelling distances greater than 6 feet (1.8 meters).<br><br>Cultivation of the isolated viral RNA could not be confirmed via Vero E6 cell assay due to low concentrations of recovered virus. However, minor indications of cytopathic effects and viral replication were observed in an air and surface sample. |
| (Zhou et al., 2020) | Investigating SARS-CoV-2 Surface and Air Contamination in an Acute Healthcare Setting During the Peak of the COVID-19 Pandemic in London. | Levels of SARS-CoV-2 surface and air contamination in a London, UK hospital at the peak of the COVID-19 pandemic was investigated.<br><br>Environmental surface swabs from clinical and public areas of the hospital were collected. Viral RNA was detected by RT-PCR in 52.3% of the collected surface samples (most often in COVID-19 patient care areas), and 38.7% of the air samples collected. Contaminated samples were more frequent in areas occupied by a COVID-19 patient.<br><br>The reclaimed virus could not be cultured in Vero E6 cell lines, as the recovered viral load was less than 30 Ct. |
| **Mathematical Models** | | |
| (Dai & Zhao, 2020)<br>*preprint* | Association of Infected Probability of COVID-19 with Ventilation Rates in Confined Spaces: a Wells-Riley Equation Based Investigation. | The Wells-Riley mathematical equation is applied to determine associations between infection probability and indoor ventilation rates. The authors report that less than 1% of the susceptible unmasked population would be infected in confined indoor spaces if the following ventilation rates and exposure periods are applied (100-350 $m^3/h$ and 1200-4000 $m^3/h$ for 15 minutes and 3 hours).<br><br>If both the infected and susceptible individuals wear masks, the ventilation rate can be reduced to 50-180 $m^3/h$ and 600-2000 $m^3/h$ correspondingly. The authors state former rates would be easier to be achieved by normal ventilation models in typical office, classrooms, buses and aircraft cabin settings. |
| **Commentaries** | | |
| (Melikov, Ai, & Markov, 2020) | Intermittent Occupancy Combined with Ventilation: An Efficient Strategy for the | Due to inherent limitations of most mechanical ventilation systems the fresh air flow supply cannot be increased to eliminate infection risk from expiratory airborne aerosols in indoor settings. As such, authors propose a source control |

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| | Reduction of Airborne Transmission Indoors. | strategy based on intermittent breaks for room occupants (i.e. all occupants leaving the room periodically) and minimized room occupancy rates to maximize the effectiveness of indoor ventilation systems reducing airborne infectious pathogens. |
| (Morawska & Cao, 2020) | Airborne Transmission of SARS-CoV-2: The World Should Face the Reality. | Based on the available evidence, the authors conclude SARS-CoV-2 can likely be transmitted via airborne route. Therefore, all possible precautions against airborne transmission in indoor scenarios should be taken. Precautions include increased ventilation rate, using natural ventilation, avoiding air recirculation, avoiding staying in another person's direct air flow, and minimizing the number of people sharing the same environment. Of significance is maximizing natural ventilation in buildings that are or can be naturally ventilated ensuring that the ventilation rate is sufficiently high. |
| (Dietz et al., 2020) | 2019 Novel Coronavirus (COVID-19) Pandemic: Built Environment Considerations To Reduce Transmission. | A review of the available evidence on the build environment that can be applied to the current COVID-19 pandemic.<br><br>SARS-CoV-2 has been observed in aerosolized particles and droplets in a range of sizes, including 0.25 to 0.5 μm, which require high efficacy filtration for removal from shared indoor air.<br><br>Residential and commercial ventilation systems with minimum efficiency reporting values (MERV) of 8 can only capture 70 to 85% of particles ranging from 3.0 to 10.0 μm (not sufficient for SARS-CoV-2 aerosols). Ventilation systems of MERV 13 or higher and HEPA filters commonly used in healthcare settings would effectively remove particle matter in the 0.25 to 0.5 μm size range. However, authors point to limitations within healthcare HVAC systems and filters arising from gaps at the edges of filters.<br><br>Overall, the authors note that although higher ventilation rates, outdoor air fractions and higher grade filters can reduce and dilute air contaminants (i.e. infectious particles) within indoor air, the risk of airborne infection transmission is never fully eliminated. |

## Table 2: COVID-19 clusters primarily attributed to indoor ventilation

| Reference | Publication Title | Key Outcomes |
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| (Lu et al., 2020) | COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China. | Indoor ventilation air flow and droplet transmission at distances less than one meter are considered to be the primary modes of transmission for a cluster (n=10) attributed to an air conditioning unit at a dine-in restaurant.<br><br>The only interaction for multiple cases in the cluster (Family B and Family C) with the index case (Family A) was sitting at neighbouring tables. In the table arrangement, the air outlet and the return air inlet for the central air conditioner were located above table of Family C, and all three tables were in line with the airflow for the same air conditioning unit.<br><br>Droplet and aerosol infection transmission linked to air conditioning air flow is considered the mode of transmission between the three families. |
| (Yuguo Li et al., 2020) *preprint* | Evidence for Probable Aerosol Transmission of SARS-CoV-2 in a Poorly Ventilated Restaurant. | A thorough follow-up analysis of the restaurant outbreak by computer simulations and aerodynamic analysis concludes transmission to be consistent with a viral spread from poor ventilation, air flow zones created by the air condition unit, and index case exhaled virus-laden respiratory particles. |
| (Almilaji & Thomas, 2020) *preprint* | Air Recirculation Role in the Infection with COVID-19, Lessons Learned from Diamond Princess Cruise Ship. | Based on the analysis of clinical data from cruise ship passengers, symptomatic infections diagnosed after the initiation of quarantine was the same in cabins with and without an infected person. The authors' conclude airborne transmission of SARS-CoV-2 through the ventilation system of the cruise ship could explain infection rates observed during the quarantine period. |
| (Xu et al., 2020) *preprint* | Transmission Routes of COVID-19 Virus in the Diamond Princess Cruise Ship. | Analysis of passenger and COVID-19 case data (n=343) from the Diamond Princess cruise ship cluster, considered the HVAC and sewage systems of the ship and the epidemiological risk factors of each case and close contact to explore the most plausible modes of transmission.<br><br>Based on the analyses the authors conclude the cruise ship's air condition (HVAC) system did not play a role in long-range airborne transmission of COVID-19 on the ship and that most passenger cases were likely exposed prior to the ship being quarantined. |

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| (Shen et al., 2020)<br>*preprint* | Airborne Transmission of COVID-19: Epidemiologic Evidence from Two Outbreak Investigation. | Airborne transmission by aerosols is assumed to be enhanced by fans and air conditioning units (re-circulating air) in shared transportation and indoor spaces and to have contributed to two independent COVID-19 outbreaks. One involving bus riders to and from a worship event (n=172), and another involving a three day conference workshop (n=30) where attendees shared indoor meeting space.<br><br>In the worship, event outbreak COVID-19 infection risk among Bus #2 passengers was 41.5 (95% CI: 2.6–669.5) times higher compared to Bus #1 passengers and 11.4 (95% CI: 5.1–25.4) times higher compared to all other individuals attending the worship event. The overall attack rate from the conference outbreak was 48.3%. |

### Table 3: Grey literature on COVID-19 transmission and HVAC systems

| Reference | Organization | Key statements |
|---|---|---|
| (ASHRAE, 2020)<br><br>Accessed here | American Society of Heating, Refrigerating, and Air-Conditioning Engineers | ASHRAE Position Document on Infectious Aerosols released in April 2020.<br><br>Transmission of SARS-CoV-2 through the air is sufficiently likely and airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating and air conditioning systems can reduce airborne exposures. Ventilation and filtration provided by HVAC systems can reduce airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. |
| (CSA Group, 2020)<br>Accessed here | CSA Group | HVAC equipment (intended for healthcare settings) testing and certification standards for manufacturers.<br><br>Standard CSA Z317.2:19: Special requirements for HVAC systems in health care facilities<br><br>Standard CAN/CSA-Z317.13-17: Infection control during construction, renovation, and maintenance of health care facilities, among others. |

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| (CDC, 2020)<br>Accessed here | Center for Disease Control and Prevention | Expert guidance on preparations and reopening businesses reference ASHRAE statement on HVAC systems, and HVAC start up guide.<br><br>The guidance alludes to ensuring HVAC systems are operating properly. Increasing circulation of outdoor air by opening windows and doors after assessing the risks of outdoor air to occupants.<br><br>Additional recommendations outlined in the documents include: increasing airflow supply to occupied spaces, disabling demand-control ventilation controls that reduce air supply based on temperature or occupancy, using natural ventilation, improving central air filtration, running the ventilation system during unoccupied times, generating clean-to-less-clean air movement, considering using portable high-efficiency particulate air (HEPA) fan/filtration systems, ensuring exhaust fans in restroom facilities are functional and operating, and considering using ultraviolet germicidal irradiation as a supplement. |
| (ECDC, 2020)<br>Accessed here | European Center for Disease Prevention and Control | Guidance on heating, ventilation and air-conditioning systems in the context of COVID-19. The document covers maintenance, avoidance of recirculation, fan direction, and air exchange rate. |
| (AHS, 2020)<br>Accessed here | Alberta Health Services | Rapid Evidence Report<br><br>Outlines the available evidence and grey literature on COVID-19 transmission and HVAC systems in healthcare and non-healthcare settings, up to May 11, 2020. The key findings from the evidence review state HVAC system factors may contribute to pathogen transmission, especially when HVAC systems are not operating properly. The exact potential of HVAC systems to contribute to SARS-CoV-2 infection transmission could not be assessed due to limited evidence on viable virus in air samples, variability in HVAC systems, and complexities in transmission modalities.<br><br>The Reviewer Committee recommend a committee with the necessary expertise be established to explore the role of |

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| | | HVAC systems in the transmission of viral pathogens including SARS CoV-2. |

### Table 4: Other Infection transmission (not SARS-CoV-2) and HVAC systems

| Reference | Publication Title | Key Outcomes |
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| (Wong et al., 2004) | Cluster of SARS Among Medical Students Exposed to Single Patient, Hong Kong. | SARS outbreak at a Hong Kong hospital isolation ward, among healthcare workers is described.<br><br>Epidemiological data of exposed healthcare workers, an inspection of the ventilation system, and computational fluid dynamic analysis find index patient's cubicle had the highest supply flow rate, while the adjacent exhaust grille had the lowest flow rate among all four functional exhaust grilles in the ward. The authors discuss the possibility of aerosol transmission from the index patient via the ventilation system. |
| (Y Li et al., 2005) | Role of Air Distribution in SARS Transmission During the Largest Nosocomial Outbreak in Hong Kong. | A second retrospective analysis of in-patient cases and healthcare worker cases from the above SARS hospital outbreak is detailed.<br><br>On-site inspections, measurements of the ventilation design and air distribution, and computational fluid dynamics simulations conclude airflow rate imbalances and non-functional HVAC system components (e.g. supply diffusers and exhaust grilles) to have contributed to infection transmission.<br><br>The analysis revealed the need for improved ventilation and air-conditioning systems in the isolation ward to effectively reduce the risk of infection spread between patients and health care workers. |
| (Satheesan et al., 2020) | A Numerical Study of Ventilation Strategies for Infection Risk Mitigation in General Inpatient Wards. | Simulations are applied to examine the transport mechanisms and deposition patterns of MERS-CoV within a general ward.<br><br>The authors concluded that air change and exhaust airflow rates had significant impacts on airflow and particle distribution. |

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| | | Within the mechanically vented space, exhaust grilles near a patient (ideally above each patient's bed), and high exhaust airflow rates are recommended to reduce transmission. |
| (Haselbach et al., 2009) | Airborne Transmission via HVAC of Acute Respiratory Infections in Military Facilities? Review of a Basic Training Cohort Study. | Examination of acute respiratory infections among military recruits living in military barracks, while considering HVAC system configurations and the sum of occupants from multiple zones that share return air mixed within the same HVAC system and redistributed as supply (termed contact population).<br><br>The study found significant risk of airborne ARI transmission through HVAC systems. Higher rates of infection were found in the systems with both higher HVAC contact populations and less access to windows allowing for outside ventilation and air supply. |
| (Sundell et al., 2011) | Ventilation Rates and Health: Multidisciplinary Review of the Scientific Literature. | A multidisciplinary review team explore the evidence (published up to 2005) linking ventilation rate to multiple health endpoints. The evidence show biological plausibility for an association of health outcomes with ventilation rates, but does not provide clear evidence on particular agent(s) or infectious loads. |
| (Y. Li et al., 2007) | Role of Ventilation in Airborne Transmission of Infectious Agents in the Built Environment - a Multidisciplinary Systematic Review. | Review of literature published between 1960 and 2005 identified ten articles linking infection transmission to HVAC systems. The reviewers conclude there is strong and sufficient evidence to demonstrate an association between ventilation, air movements in buildings and the transmission/spread of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox and SARS. However, there was insufficient data to specify and quantify the minimum ventilation requirements in hospitals, schools, offices, homes and isolation rooms in relation to spread of infectious diseases via the airborne route. |

# Methods:

A daily scan of the literature (published and pre-published) is conducted by the Emerging Science Group, PHAC. The scan has compiled COVID-19 literature since the beginning of the outbreak and is updated daily. Searches to retrieve relevant COVID-19 literature are conducted in Pubmed, Scopus, BioRxiv, MedRxiv, ArXiv, SSRN, Research Square and cross-referenced with the literature on the WHO COVID literature list, and COVID-19 information centers run by Lancet, BMJ, Elsevier and Wiley. The daily summary and full scan results are maintained in a Refworks database and an Excel list that can be searched. Targeted keyword searching is conducted within these databases to identify relevant citations on COVID-19 and SARS-CoV-2. Search terms included in this review were (indoor and air), ventilation, HVAC, air conditioning. Each potentially relevant reference was examined to confirm it relevance data and relevant data was extracted. This review contains COVID-19 research published up to August 13, 2020. Relevant literature predating COVID-19 was identified by examining the reference lists of the relevant reviews and papers included in this summary.

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