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Ventilation Strategies to improve Indoor Air Quality and Occupant Safety from Covid-19: A Review

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Abstract

Researchers have been studying the impact of the recent pandemic on the occupants of the built environment with the advancement of COVID-19. As people spend more time indoors in their day-to-day lives, and as coronavirus is airborne, several indoor air quality parameters are responsible for its spread. This paper investigates the role that poor indoor air quality plays in the spread of epidemics and looks into ventilation strategies that could improve occupant safety in indoor settings in the case of an epidemic crisis in the future. The study included a review of the literature on ventilation strategies to enhance the indoor air quality for occupant safety from COVID-19 of the 121 documents that were retrieved, 39 were found suitable and were further investigated. The study outlined several steps to prevent the pandemic from spreading in an indoor environment. Regular hygiene measures included keeping the interior environment clean, safe, and comfortable with fewer chemical and biological agents. Measures related to space design and usage included better ventilation, air filtering, and social distancing.

Discipline: Building Science, Environment.

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1 Introduction

The recent pandemic has left an unprecedented impact on human health throughout the world. Since its inception in December 2019, Corona Virus Disease spread globally and marked around 570 million confirmed cases and 6.3 million deaths by July 2022 (WHO, 2022). Patients with

diabetes, high blood pressure, and chronic respiratory diseases were more susceptible to the infection (Zheng et al., 2020). Early symptoms of COVID-19 begin with an upper respiratory tract infection and the production of aerosols through conversation. Numerous studies that sought to reduce the coronavirus's infectivity investigated its transmission mechanisms. The virus is mostly disseminated through touch and aerosol inhalation, which can have mild to severe respiratory consequences (Carlsten et al., 2021; Petroni et al., 2020; Singh & Singh, 2020). The aerosol transmits through sneezing, coughing, speaking, breathing, etc. Since the virus is persistent on surfaces for hours, it increases the likelihood of transmitting the disease (Onakpoya et al., 2021).

There have been studies about the implications of the built environment on the spread of COVID-19. Lack of outdoor infrastructure and basic amenities, clustered dwellings, and public transportation also affected the surge of the pandemic (Das et al., 2021; Li et al., 2021). Different indoor built environments also have vivid impacts on the rate of infection due to the activeness of the virus (Velraj & Haghighat, 2020). More than 80% of aerosols produced during speaking and breathing are less than 1 µm (LJGR Morawska et al., 2009). Proper ventilation can reduce the chances of spreading the pandemic due to a lower concentration of infectious aerosols. Several ventilation systems are responsible for the hike of COVID-19 while proper ventilation strategies can reduce the risk of infection. Improper ventilation may cause microbial contamination in an indoor space and deteriorates the environment. There is no consensus about the minimum amount of ventilation to minimize the risk of an epidemic. However, REHVA (The Federation of European Heating, Ventilation and Air Conditioning associations) and SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers) suggested reducing the Co_2 concentration (Navaratnam et al., 2022). Monitoring the ventilation strategies, therefore, becomes necessary to stop the pandemic from spreading. This paper examines the various ventilation methods that can enhance the safety of occupants from pandemics in indoor spaces.

2 Method

A literature review was conducted to study ventilation strategies to improve indoor air quality for the occupant's safety from COVID-19. The research database of Web of sciences and ScienceDirect were used to search a set of keywords. The keywords included the Boolean operators "AND" and "OR" to combine the following search words: Covid-19, indoor environment, indoor air quality, occupant's health, built environment, ventilation strategies, aerosols, occupants' safety, displacement ventilation, mixing ventilation, ventilation kinds, sick building syndrome, artificial ventilation and natural ventilation (Table1). Using the key search words, 121 documents were retrieved based on their relevance. Among them, 20 were review papers, 90 were original research papers and 11 were manuals. Inclusion criteria were from the potential use of ventilation strategy to improve indoor air quality and to reduce the risk of a pandemic. As COVID-19 was the base of the research, the works published between 2019 and 2022 were included. In a case where the indoor and outdoor environments were studied, only studies related to the indoor environment were considered. After a rigorous review, 39 documents were studied to investigate ventilation strategies

during the pandemic. Authors anticipated that the included published works would not have conducted meta-analyses and planned to present results in narrative form.

Table 1: Search string used for review

Year	Sources	Search String
2019-2022	ScienceDirect(Title, Abstract and Keywords) and Web of Science (All fields)	("Built environment" OR "building" OR "Indoor environment quality" OR Indoor air quality" OR "Sick building syndrome" OR Occupant's health" OR "Occupant's safety" OR "Aerosoles) AND ("covid19" OR "Covid19" OR "COVID-19" OR "Covid") AND ("Ventilation strategies" OR "Ventilation kind" OR "Mixing ventilation" Displacement ventilation" OR "Artificial ventilation" OR Natural ventilation")

3 Literature Review

According to the review, the corona pandemic infection is significantly facilitated by indoor air quality. The indoor environment should therefore be clean, safe and comfortable with less exposure to chemical and biological agents to prevent disease. The studies indicate that the virus is passive in high humidity and high temperatures (Ahlawat et al., 2020). With the advancement of Covid-19, scholars around the globe investigated the effect of a recent pandemic on the built environment and its occupants (Kannan et al., 2020; Martinez-Alvarez et al., 2020; Mehta et al., 2020). Several studies indicate that COVID-19 spreads primarily in crowded indoor spaces, while the risk is lower in open spaces (Park et al., 2020; Qian et al., 2021). Qian et al. (2021) collected data on 7324 cases from 320 cities in mainland China and summarized that 318 identified outbreaks that involved three or more cases, all occurring in an indoor environment. The possibility of virus transmission is greater in confined indoor crowded environments such as commercial, religious, and recreational spaces (Leclerc et al., 2020). Indoor Air Quality (IAQ) has consequently assumed more significance, due to the potential for aerosols to act as coronavirus carriers in indoor spaces (Lu et al., 2020; Stadnytskyi et al., 2020). Melikov et al. (2020) recommended that the infection probability may be reduced with the supply of clean outdoor air and a moderate increase in room height. Air dilution through ventilation is one of the strong and effective strategies to reduce infection risk in an indoor environment.

Research evidence suggests that the coronavirus is an airborne disease, and droplets are the transmission route for the infection (Noorimotlagh et al., 2021; Organization, 2020). Human exhalation is the primary cause of the spread of respiratory diseases, which contain droplets ranging from 0.01 to 1000 μm in size (Bake et al., 2019). Droplets less than 5 μm are classified as aerosols that remain suspended in the air for a longer period and larger droplets settle toward the floor (Milton, 2020). These aerosols are produced by intermittent coughing and sneezing. However, the asymptomatic epidemic in congested areas has demonstrated that aerosols can also be transmitted by talking or breathing. According to research, the virus remains active in the air for about 3 hours. (Somsen et al., 2020). The rate of exhalation is influenced by the aerosol size, composition, humidity, and air temperature. Somsen et al. (2020) experimented with measuring

airborne time and the size of droplets during cough and speech in relation to ventilation. They found that from a 1.6m height, the aerosols take 9 minutes to reach the floor. A well-ventilated space can reduce the suspension time of aerosols in the air. Air exchange between indoor and outdoor spaces dilutes air contaminants (Lidia Morawska et al., 2020). In a study of a hospital room with three patients, 12 air exchanges per hour resulted in negative air samples for viruses (Ong et al., 2020). High-intensity of fresh air ventilation through various intake ventilation strategies has been found effective in various research in reducing viral transmission (Nembhard et al., 2020; Santos et al., 2020). However, enhancing fresh air ventilation through mechanical means may increase energy consumption.

Airflow pattern is responsible for transmission and contamination. Lu et al. (2020) investigated an air-conditioned restaurant in Guangzhou with a dining area of 145 square meters where the distance between tables was 1 meter. Ten visitors out of 83 were infected with Covid19 due to recirculated air in a windowless area. The study also showed that with an improved displacement ventilation system, energy consumption and infectivity could be reduced in comparison to mixing ventilation (Chen et al., 2020). The displacement ventilation system with partition may reduce the risk of infection by up to 96% (Tambyah et al., 2021). In an aircraft passenger cabin, a combination of displacement ventilation and mixing ventilation (50%DV+50%MV) provides a more comfortable, satisfactory and healthy environment (Maier et al., 2017).

Park, Choi, Song, and Kim (2021) use Wells –Riley equation to analyse the natural ventilation performance in a school building and the findings show when a mask is worn and more than 15% of windows are open with cross ventilation the infection probability is less than 1%. However, the infection probability increase with exposure time. It is experimentally proven that there is a decrease of 400 ppm in Co_2 weekly during the pandemic with natural ventilation while 300 ppm in the case of hybrid ventilation (Alonso et al., 2021). However, natural ventilation may lead to thermal discomfort if the weather conditions are adverse.

4 Result and Discussion

The pandemic infectivity may be transmitted either directly through aerosols or indirectly through contact transfer. The mode of transmission of the disease also depends on the severity and location of the infection in the respiratory tract (Somsen et al., 2020). However, a low concentration of aerosols with high temperature and humidity might enhance the spread of coronavirus. The spread of COVID-19 can be controlled by hand washing, sanitization, social distancing, proper ventilation, and air filtration. Hand washing with soap or sanitizer is the most simple and primary prevention for stopping the spread of infection. Social distancing is one of the effective tools to control the rate of spread of the epidemic. However, social distancing may lead to social instability, and consequently, some people may undergo anxiety and depression.

Inadequate ventilation in enclosed spaces can contribute to the spread and transmission of infectious diseases. Poor indoor air quality has an impact on efficiency, social productivity, and

work performance, while also increasing the likelihood of the epidemic spreading. To avoid health hazards, it is necessary to improve indoor air quality. With the spread of COVID-19, planning proper ventilation becomes even more important. Fresh air dilutes pollutants in the air, while exhaust air removes them from the indoor environment. However, before feeding in a closed space air must be filtered and exchanged with fresh air. The primary objective of filtering is to remove microbes and viruses carried by small particles in the supplied air. Scholars dealing with the emerging coronavirus epidemic must examine building ventilation systems.

Indoor ventilation has two modes: displacement ventilation and mixing ventilation. In displacement ventilation, fresh air is added near the floor at a lower speed which stratifies the air vertically and removes warm air near the ceiling. In mixing ventilation the outdoor high-velocity air is provided above the occupant's zone which distributes the air evenly throughout the space. The purpose of mixing ventilation is to get a steady and uniform indoor environment. Poor ventilation in a built environment leads to the spread of airborne diseases such as SARS and tuberculosis (Y. Li et al., 2007). Displacement ventilation is the process of spreading a layer of clean air on the ground, which rises upward and exhausts through a vent near the ceiling (Yuan et al., 1999). In this process, buoyancy is created as a result of temperature and air density variations. Displacement ventilation is suitable for lighter pollutants and high-temperature. Displacement ventilation provides good air quality in the occupied zone, while thermal comfort is affected by the stratification of temperature (Tian et al., 2019).

The position of the inlet of HVAC becomes more critical in case of the spread of the epidemic in a conditioned space. In mixing ventilation, the inlet and outlet of air are arranged in such a manner that the temperature and other contaminants of the air are evenly spread in the space. Mixing ventilation prevents the stratification of displacement ventilation, and does not provide a clean zone by distributing the air throughout the space. Mixing ventilation has a risk of inhaling airborne infectious disease viruses from the infected occupants.

5 Conclusion

To improve occupant safety during the pandemic, this study reviewed the literature to explore ventilation strategies in indoor spaces. Studies show that there is a strong relationship between ventilation and infection probability. To improve IAQ, a uniform distribution of air throughout the room is essential as it dilutes the concentration of contaminants (Zhang, 2020). Proper ventilation and frequent air renewal must be ensured for the mitigation of epidemic spread. The rate and the pattern of the airflow from the clean zone to the dirty zone is the basic principle to control pollutants. Ventilation rate is a measure of how much outdoor air is supplied into a building. Fresh air intake with high intensity reduces the risk of viral transmission.

The high fan speed also lowers the concentration of contamination. The ceiling fan, through the dispersion of the aerosols, reduces the individual breathing zone's concentration by 20 per cent. Wall-based attached ventilation reduces the average concentration of contamination. However, the use of personal ventilation is more effective as it keeps the contamination to a

limited area and reduces the risk of epidemic spread to other areas. Displacement ventilation encourages the flow of air from the floor toward the ceiling and keeps away airborne contagion from the occupants as the foul air escapes from the vent near the ceiling (Bhagat et al., 2020). Mixed ventilation blends the fresh air with contaminated air which further increases the risk of transmission in the occupied zone. However, the stratified air in displacement ventilation does not allow mixing the contaminants throughout the space which reduces the risk of the spread of infection. The spaces are ventilated mechanically to improve thermal comfort and reduce the pollutants in the air. Displacement ventilation reduces the risk of pandemic spread in comparison to mixed ventilation.

The recirculation of the air in an HVAC system may increase the rate of infection, and the situation can be worst in the case of a centralized air-conditioning system. However, the proper maintenance and functioning of the HVAC system may reduce the risk of an epidemic. Purifiers are also used to keep the infection away in the mechanical system of ventilation. Energy efficiency and air purification have become dual challenges when using mechanical ventilation, keeping in mind the thermal comfort of occupants with the spread of the pandemic. Poorly ventilated buildings have more risk of spreading a pandemic while achieving occupant comfort without excessive energy consumption is the need of the hour.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

7 References

Ahlawat, A., Wiedensohler, A., & Mishra, S. K. (2020). An overview on the role of relative humidity in airborne transmission of SARS-CoV-2 in indoor environments. Aerosol and Air Quality Research, 20(9), 1856-1861.

Alonso, A., Llanos, J., Escandón, R., & Sendra, J. J. (2021). Effects of the Covid-19 pandemic on indoor air quality and thermal comfort of primary schools in winter in a Mediterranean climate. *Sustainability*, *13*(5), 2699.

Bake, B., Larsson, P., Ljungkvist, G., Ljungström, E., & Olin, A.-C. (2019). Exhaled particles and small airways. Respiratory research, 20(1), 1-14.

Bhagat, R. K., Wykes, M. D., Dalziel, S. B., & Linden, P. (2020). Effects of ventilation on the indoor spread of COVID-19. Journal of Fluid Mechanics, 903.

Carlsten, C., Gulati, M., Hines, S., Rose, C., Scott, K., Tarlo, S. M., . . . de la Hoz, R. E. (2021). COVID-19 as an occupational disease. American Journal of Industrial Medicine, 64(4), 227-237.

Chen, C., Lai, D., & Chen, Q. (2020). Energy analysis of three ventilation systems for a large machining plant. Energy and buildings, 224, 110272.

Das, A., Ghosh, S., Das, K., Basu, T., Dutta, I., & Das, M. (2021). Living environment matters: Unravelling the spatial clustering of COVID-19 hotspots in Kolkata megacity, India. Sustainable Cities and Society, 65, 102577.

Kannan, S., Ali, P. S. S., Sheeza, A., & Hemalatha, K. (2020). COVID-19 (Novel Coronavirus 2019)-recent

trends. Eur Rev Med Pharmacol Sci, 24(4), 2006-2011.

Leclerc, Q. J., Fuller, N. M., Knight, L. E., Funk, S., Knight, G. M., & Group, C. c.-W. (2020). What settings have been linked to SARS-CoV-2 transmission clusters? Wellcome open research, 5.

Li, B., Peng, Y., He, H., Wang, M., & Feng, T. (2021). Built environment and early infection of COVID-19 in urban districts: A case study of Huangzhou. Sustainable Cities and Society, 66, 102685.

Li, Y., Leung, G. M., Tang, J., Yang, X., Chao, C., Lin, J. Z., . . . Qian, H. (2007). Role of ventilation in airborne transmission of infectious agents in the built environment-a multidisciplinary systematic review. Indoor air, 17(1), 2-18.

Lu, J., Gu, J., Li, K., Xu, C., Su, W., Lai, Z., . . . Yang, Z. (2020). COVID-19 outbreak associated with air conditioning in restaurant, Guangzhou, China, 2020. Emerging infectious diseases, 26(7), 1628.

Maier, J., Marggraf-Micheel, C., Dehne, T., & Bosbach, J. (2017). Thermal comfort of different displacement ventilation systems in an aircraft passenger cabin. Building and Environment, 111, 256-264.

Martinez-Alvarez, M., Jarde, A., Usuf, E., Brotherton, H., Bittaye, M., Samateh, A. L., . . . Roca, A. (2020). COVID-19 pandemic in west Africa. The lancet global health, 8(5), e631-e632.

Mehta, P., McAuley, D. F., Brown, M., Sanchez, E., Tattersall, R. S., & Manson, J. J. (2020). COVID-19: consider cytokine storm syndromes and immunosuppression. The lancet, 395(10229), 1033-1034.

Melikov, A. K., Ai, Z., & Markov, D. (2020). Intermittent occupancy combined with ventilation: An efficient strategy for the reduction of airborne transmission indoors. Science of The Total Environment, 744, 140908.

Milton, D. K. (2020). A Rosetta Stone for understanding infectious drops and aerosols (Vol. 9, pp. 413-415): Oxford University Press US.

Morawska, L., Johnson, G., Ristovski, Z., Hargreaves, M., Mengersen, K., Corbett, S., . . . Katoshevski, D. (2009). Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities. Journal of aerosol science, 40(3), 256-269.

Morawska, L., Tang, J. W., Bahnfleth, W., Bluyssen, P. M., Boerstra, A., Buonanno, G., . . . Franchimon, F. (2020). How can airborne transmission of COVID-19 indoors be minimised? Environment international, 142, 105832.

Navaratnam, S., Nguyen, K., Selvaranjan, K., Zhang, G., Mendis, P., & Aye, L. (2022). Designing post COVID-19 buildings: Approaches for achieving healthy buildings. *Buildings, 12*(1), 74.

Nembhard, M. D., Burton, D. J., & Cohen, J. M. (2020). Ventilation use in nonmedical settings during COVID-19: Cleaning protocol, maintenance, and recommendations. *Toxicology and industrial health, 36*(9), 644-653.

Noorimotlagh, Z., Jaafarzadeh, N., Martínez, S. S., & Mirzaee, S. A. (2021). A systematic review of possible airborne transmission of the COVID-19 virus (SARS-CoV-2) in the indoor air environment. Environmental Research, 193, 110612.

Onakpoya, I. J., Heneghan, C. J., Spencer, E. A., Brassey, J., Plüddemann, A., Evans, D. H., . . . Jefferson, T. (2021). SARS-CoV-2 and the role of fomite transmission: a systematic review. F1000Research, 10.

Ong, S. W. X., Tan, Y. K., Chia, P. Y., Lee, T. H., Ng, O. T., Wong, M. S. Y., & Marimuthu, K. (2020). Air, surface environmental, and personal protective equipment contamination by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) from a symptomatic patient. Jama, 323(16), 1610-1612.

Organization, W. H. (2020). Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations: scientific brief, 29 March 2020. om

Park, S., Choi, Y., Song, D., & Kim, E. K. (2021). Natural ventilation strategy and related issues to prevent coronavirus disease 2019 (COVID-19) airborne transmission in a school building. Science of The Total Environment, 789, 147764.

Park, S. Y., Kim, Y.-M., Yi, S., Lee, S., Na, B.-J., Kim, C. B., Park, Y. (2020). Coronavirus disease outbreak in call center, South Korea. Emerging infectious diseases, 26(8), 1666.

Petroni, M., Hill, D., Younes, L., Barkman, L., Howard, S., Howell, I. B., Collins, M. B. (2020). Hazardous air pollutant exposure as a contributing factor to COVID-19 mortality in the United States. Environmental Research Letters, 15(9), 0940a0949.

Qian, H., Miao, T., Liu, L., Zheng, X., Luo, D., & Li, Y. (2021). Indoor transmission of SARS-CoV-2. Indoor air, 31(3), 639-645.

Santos, A. F., Gaspar, P. D., Hamandosh, A., Aguiar, E. B. d., Guerra Filho, A. C., & Souza, H. J. L. d. (2020). Best practices on HVAC design to minimize the risk of COVID-19 infection within indoor environments. *Brazilian Archives of Biology and Technology, 63*.

Singh, J., & Singh, J. (2020). COVID-19 and its impact on society. Electronic Research Journal of Social Sciences and Humanities, 2.

Somsen, G. A., van Rijn, C., Kooij, S., Bem, R. A., & Bonn, D. (2020). Small droplet aerosols in poorly ventilated spaces and SARS-CoV-2 transmission. The Lancet Respiratory Medicine, 8(7), 658-659.

Stadnytskyi, V., Bax, C. E., Bax, A., & Anfinrud, P. (2020). The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. Proceedings of the National Academy of Sciences, 117(22), 11875-11877.

Tambyah, P. A., Conly, J., & Voss, A. (2021). Community Outbreak Investigation of SARS-CoV-2 Transmission Among Bus Riders in Eastern China. *JAMA internal medicine, 181*(5), 719-720.

Tian, X., Li, B., Ma, Y., Liu, D., Li, Y., & Cheng, Y. (2019). Experimental study of local thermal comfort and ventilation performance for an office's mixing, displacement and stratum ventilation. Sustainable Cities and Society, 50, 101630.

Velraj, R., & Haghighat, F. (2020). The contribution of dry indoor built environment on the spread of Coronavirus: Data from various Indian states. Sustainable Cities and Society, 62, 102371.

WHO. (2022) Coronavirus disease (COVID-19) dashboard. Retrieved from https://covid19.who.int/ on July 2022.

Yuan, X., Chen, Q., Glicksman, L. R., Hu, Y., & Yang, X. (1999). Measurements and computations of room airflow with displacement ventilation. Ashrae Transactions, 105(1), 340-352.

Zhang, J. (2020). Integrating IAQ control strategies to reduce the risk of asymptomatic SARS CoV-2 infections in classrooms and open plan offices (Vol. 26, pp. 1013-1018): Taylor & Francis.

Zheng, Y., Ma, Y., Zhang, J., & Xie, X. (2020). COVID-19 and the Cardiovascular System (Vol. 17, pp. 259-260): Nature Reviews Cardiology.

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