

Influence of Ventilation in Healthcare Facilities Prevention of Infection COVID-19: Systematic Review Study

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ABSTRACT

Currently, (2019-2020) COVID-19 global pandemic is caused by a member of the Coronaviridae group. Some human viruses are spread from human to human by way of droplets or aerosols, but fewer viruses are persistently airborne in transmission, and the healthcare-associated epidemic of airborne viral infection are restricted to very few surrogates. In addition, it is one of the most efficient tools (i.e., the second one) for preventing inside air pollution through ventilation. To our aim was to perform a rapid literature review to answer the following question: does ventilation in healthcare facilities prevention of infection COVID-19?

This study is a systematic review by searching among published articles in Embase, PubMed/MEDLINE, Scopus, PubMed Central (PMC), Google Scholar databases as well as medRxiv by using the following keywords: 'COVID-19', 'healthcare settings', 'prevention', 'ventilation', 'Hospital', 'Infection', and 'Air changes per hour.

After investigating the information and quality of articles, 52 articles were included in this study. The literature denotes that temperature, relative humidity, and ventilation and air conditioning systems have beneficial effects to prevent COVID-19 infection.

The results of this study demonstrated that many parameters basic strategy of control COVID-19 include: hand hygiene, social distancing, screening and case finding, isolation and separating, decontamination and disinfection, and effective ventilation. Thus, based on recommendations of CDC, WHO, and other studies effective ventilation is the most important transmission of respiratory disease control strategy, specially COVID-19.

Keywords: coronaviruses infections, prevention and control, ventilation

INTRODUCTION

Initially, COVID-19 that begun at the end of 2019 has turned into a pandemic. According to the evidence, its main ways of transmission are person-to-person and viral droplets (>5–10 µm in diameter) of infected patients, or sings at short distances, commonly <1–2 m. However, there are doubts about its transmission through (<5 µm in diameter), remaining infectious when suspended in the air over long distances and time (Chirico et al., 2020). It worth noting that personal hygiene and avoiding infected surfaces is of crucial importance. Ventilation is a principal infectious disease prevention method in health care centers and other facilities, using a suitable HVAC (heating, ventilation, and air conditioning) system could be mitigated virulence of SARS-CoV-2.

Currently, indoor air quality (IAQ) has achieved more consideration because people are spending more time at home (70–90%), the impact of outdoor source on IAQ, and existence

of various kinds of pollutants such as total volatile organic compounds (TVOCs), household cleaning products, disinfectant sprays, particulate matter (PM), CO₂, and bioaerosols agents in IAQ (Domínguez-Amarillo et al., 2020). There are several parameters, such as origins, building construction and materials, air conditioning and its speed, inhabitant practice and functions that influence the IAQ (Harbizadeh et al., 2019). This systematic review intended to investigate does ventilation in healthcare facilities prevention of infection COVID-19?. The spread of epidemics is associated with air pollutants (carbon monoxide, sulfur oxides, nitrogen oxides, ground-level ozone, particulate matter, and lead, other pollutants (Polycyclic Aromatic Hydrocarbons (PAHs), Volatile Organic Compounds (VOCs), and Dioxins. Global climate change (greenhouse gases, ozone-depleting), and climatological factors (e.g., wind speed, temperature, humidity) (Manisalidis et al. 2020), for example, as the virus has a lipid envelope, its survival is longer in areas with lower (< 50%) relative humidity (RH) than RH >80%. The role of air pollution in the transmission of the COVID-19 virus by

aerosols is still under discussion. Researches demonstrated that there were more studies related to SARS-COV-2 transmission from hospital air from Asian countries (Iran, China, Singapore) and the highest number of researches was related to China (Aghalari et al., 2021). Many studies had been conducted on the effects from indoor air pollutants in hospitals such as carbon dioxide, carbon monoxide, formaldehyde, fungi and mold (Gola et al., 2019; Slama et al., 2019), but there is few researches on viruses in the hospitals air and role of ventilation. Correia et al. analyzed the ventilation methods and the airborne pathway of SARS-CoV-2 (Correia et al., 2020). Kim et al. also investigated the effects of humidity and other parameters on the formation of a coronavirus aerosol (Kim et al., 2007). Gola et al. investigated the mechanical ventilation in healthcare settings, and their heating, ventilation and air conditioning (HVAC) systems operation (Gola et al., 2020).

There are a few researches on how to prevent airborne COVID-19 transmission. On the other hand, the estimation of the risk of disease related with the use of air-conditioning is necessary for making correct decisions, also ventilation has a crucial role in preventing contagious diseases in healthcare facilities as well as other settings. Therefore, this fast literature review tries to provide adequate knowledge and strategies for ventilation methods and control and prevention strategies.

METHODS

Following a systematic review design, this research was conducted to evaluate can ventilation in healthcare facilities prevention of infection COVID-19? In this study used of databases of Scopus, ISI, Web of Science, Google Scholar, PubMed (MEDLINE), World Health Organization, and American Centers for Disease Control (CDC) and Prevention using MeSH (Medical Subject Headings) keywords for the period of December 2019 to April 2021. Descriptive statistics is performed categorizing. Hence, using appropriate keywords (“Coronaviruses” OR “CoV” OR “Human Coronaviruses “ OR “HCoV” OR “nCov” OR “Novel Coronaviruses “ OR “2019 Novel Coronavirus” OR “Covid-19” OR “2019-nCoV” OR “Severe Acute Respiratory Syndrome-Coronaviruses-

2”OR”SARS-COV-2”) AND (“Air pollution” OR “Air pollution “OR”Ventilation” OR “Air changes per hour” OR “healthcare facilities”) AND (“Hospital); (“indoor air quality AND COVID-19”); (“Prevention Methods” OR “Infection Prevention and Control”) the abovementioned databases were searched. Information on the authors’ name, type study, study remarks, type of setting, and main variables parameters like temperature, relative humidity, and type of ventilation and outcomes were collected. As shown in **Figure 2**, a total of 120 peer reviewed publications were accessed based on the relevance of titles to the research. These were further screened to 73 after reading through their abstracts. Following screening the full text of the articles, 52 were used for this review, excluding the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reference (Moher et al., 2010). There are several methods for measurement of ventilation rate such as: Air changes per hour, volumetric airflow per person, volumetric airflow per floor area, percent outdoor air intake, and CO₂ concentration. In this study used to air changes per hour, volumetric airflow per person, percent outdoor air intake, and CO₂ concentration methods.

Air changes per hour one significant change relates to the ventilation recommendations for patient rooms, values were estimated as follows: (World Health Organization, 2020b)

$$t_2 - t_1 = - [\ln (C_2 / C_1) / (Q / V)] * 60 \quad (1)$$

with $t_1 = 0$, where t_1 = initial time point in minutes t_2 = final time point in minutes C_1 = inlet concentration of contaminant, C_2 = outlet concentration of contaminant $C_2 / C_1 = 1 - (\text{removal efficiency} / 100)$ Q = air flow rate in cubic feet/hour

V = room volume in cubic feet $Q / V = \text{ACH}$.

In the discussion section, we discussed the most important findings in three parts included: indoor air ventilation, indoor air relative humidity, and indoor air temperature.

RESULTS AND DISCUSSION

Concentration on 10 articles, 60% (6), 20% (2), and 20% (2) were based on the simulation, experimental, and observational methods, respectively. (**Figure 1**). These articles were from

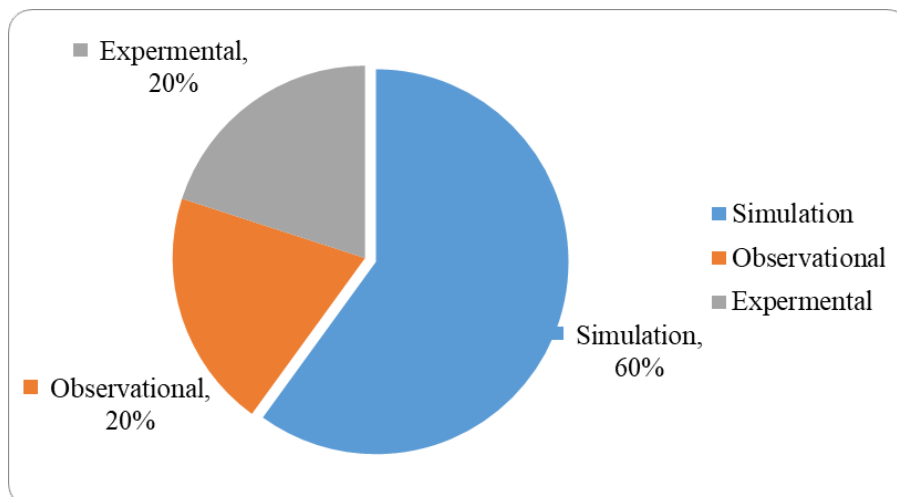


Figure 1. Condition type of design researches

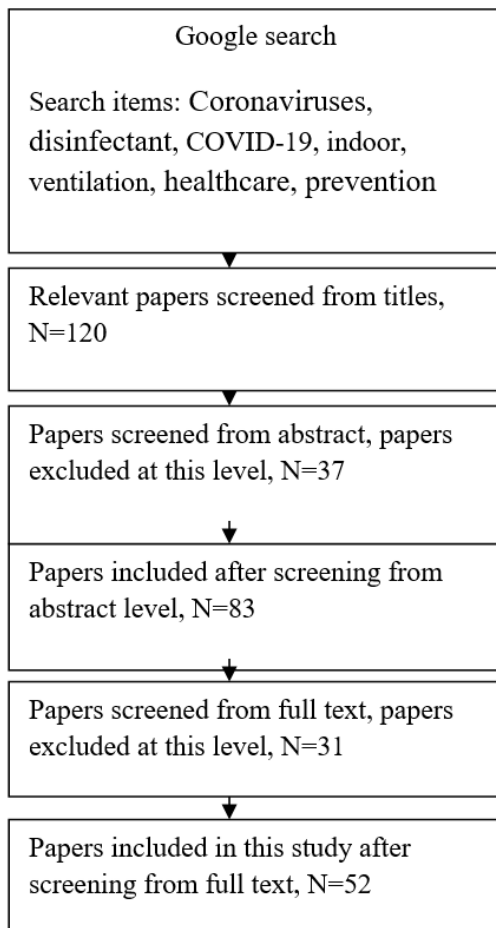


Figure 2. Chart presentation the method of the analysis process

health care/hospital (4), public buildings (3), residential places (1), dormitory (1), and offices (1). The main results are provided in **Table 3**. Based on results this study, two articles mentioned that SARS-COV-2 can be reduced by ventilation in the air hospitals, while eight noted the ventilation effect in closed areas. Demonstrated that **Tables 1** and **2** air changes/hour and outline of ventilation according to guidelines and standards of CDC and those published for controlling infection at healthcare settings.

Indoor Air Ventilation

The results of this study illustrated that there were more researches associated to SARS-COV-2 and ventilation in closed spaces. According to results, two papers mentioned that ventilation was not associated with reduced levels of SARS-COV-2 in the air of hospitals, meanwhile, eight papers reported vice versa. Hence, more studies are needed to investigate whether ventilation systems are associated with declined transmission of SARS-COV-2. In healthcare settings, ventilation strategy and air distribution model affect the transmission of contagious diseases.

There are three methods that may be used to ventilate spaces within health-care settings: natural, mechanical and combination (mixed-mode) ventilation. Any decision on climate to use natural, combination or mechanical ventilation should take into account climate, including prevalent wind path, floor plan, need, availability of resources, and the cost of the ventilation system (World Health Organization, 2020a).

In health-care settings, the ventilation rate (mechanical method) should be 6-12, ideally 12 ACH for new constructions and mean natural ventilation rate is 160 L/s/patient, with a recommended negative pressure differential of ≥ 2.5 Pa to

Table 1. Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency (Chinn and Schulster, 2003)

ACH	Time (mins.) required for removal: 99% efficiency	Time (mins.) required for removal: 99.9% efficiency
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

Table 2. Outline of ventilation characteristics in chosen areas of health-care centers (Chinn and Schulster, 2003)

Characteristics	All room (includes bronchoscopy suites)	Protective environment room	Critical care room	Isolation anteroom	Operating room
Air pressure	Negative	Positive	Positive, negative, or neutral	Positive or negative	Positive
Room air changes	≥ 6 ACH (for existing rooms); ≥ 12 ACH (fore novation or new construction)	≥ 12 ACH	≥ 6 ACH	≥ 10 ACH	≥ 15 ACH
Sealed	Yes	Yes	No	Yes	Yes
Filtration supply	90% (dust-spot ASHRAE52.1 1992)	99.97% (Fungal spore filter at point of use (HEPA at 99.97% of 0.3 μ m particles))	>90%	>90%	90%
Recirculation	No (Recirculated air may be used if the exhaust air is first processed through a HEPA filter.)	Yes	Yes	No	Yes

Table 3. Most important characteristics of reviewed papers

Type study	Type setting	Remarks	Reference
Simulation	Public buildings	A minimum RH standard of 40% for populated spaces not only decrease the effect of the virus, but also can decrease the effect of more viral infections, both arid and moist places.	(Ahlawat et al., 2020)
Simulation	Public buildings	There is a major and firm possibility of airborne spread of COVID-19 in indoor air ambient	(Noorimotlagh et al., 2020)
Simulation	Hospitals	Ventilation has a major impact on SARS-CoV-2 spread	(Chen et al., 2011)
Experimental	Residential Indoor	Action programs should be promoted for the reinstatement or enhancement of the filtration systems of the air-conditioning and heating systems in houses	(Domínguez-Amarillo et al., 2020)
Simulation	Patient Rooms	Increase ventilation rates were not causes reduce aerosol concentrations	(Mousavi and Grosskopf, 2015)
Experimental	Hospitals	The few COVID-19 studies did not provide adequate indication that the virus may be spread by HVAC systems.	(Chirico et al., 2020)
Observational	Dormitory	CO ₂ mean level was 1230 ± 408 ppm and 1492 ± 837 ppm in the two dormitory buildings.	(Zhu et al., 2020)
Simulation	Public buildings	Use of engineering controls in populated spaces such as: separating infected individuals, opening windows and doors, and using moveable air-cleaning devices when practicable	(Morawska et al., 2020)
Observational	Health care centers	Simple changes in hospital structure noticeably enhanced natural ventilation, and seriously decreased air borne infection risk at little cost	(Escombe et al., 2019)
Simulation	Offices	Relationship among air conditioning and sick building syndrome (SBS) signs in various rooms, where higher ventilation rates, up to about 25 l/s per capita, are related with decreased symptoms	(Sundell et al., 2011)

guarantee air flows from the corridor into the rooms designed for hospitalizing patients (Feng et al., 2020; World Health Organization 2020b). Ventilation (>6 ACH) can guarantee both negative pressure difference (> 2.5 Pa) and airflow difference (> 56 L/s) (Table 1) (Control and Prevention; Jayaweera et al. 2020). Upgrading ventilation of health care centers will dilution and removal potentially infectious aerosols (Somsen et al., 2020).

The maximum ventilation rates in liter per second per person (l/s/p) of 5 and air exchange velocity of 0.04 m/s in most school buildings, restaurants and offices (Amoatey et al., 2020).

Inappropriate use of ventilation systems has severe negative effects on transmission of COVID-19 (Correia et al., 2020). Effective ventilation is a major technique to prevent expansion of contagious disease, improved ventilation may be a key factor in prevention the spread of the SARS-CoV-2 virus (Gola et al., 2020). One study showed that good mechanical room ventilation using outdoor air would have an effect similar to a 50–60% vaccination coverage in a poor ventilation system (Spena et al., 2020).

One research demonstrated that the majority of COVID-19 patients infected at home became infected in a cold, air conditioned, arid, and bad-ventilated indoor condition. Masoumbeigi and colleagues mentioned that mechanical air conditioning and natural ventilation are available methods that can be used for air cleaning in hospitals (Masoumbeigi et al., 2020). Masoumbeigi and colleagues and Faridi and colleagues illustrated that ventilation (either mechanical or natural) were applied in healthcare facilities (Faridi et al., 2020; Masoumbeigi et al., 2020). In a study by Salonen et al. (2014) ventilation air conditioning system is principal to maintain negative pressure within separation rooms, to protect the health of staff, patients and visitors, as well as to control patients' risk for airborne diseases (Salonen et al., 2013). One study reported that Indoor aerosol levels are

strongly dependent on the availability and operation of ventilation and filtering installations (Dobricic et al., 2020). In a study by Ahlawat et al. (2020) the transmission pathways of SARS-CoV-2 are still discussed, but recent evidence strongly proposes that COVID-19 could be transmitted via air in places poor ventilation (Ahlawat et al., 2020). One study showed that appropriate ventilation and the use of separate ventilation devices for SARS-COV-2 patients were introduced as effective systems to prevent the SARS-COV-2 transmission (Liu et al., 2020). In a study by Chirico et al. (2020) the studies available to date are not sufficient to support the conclusion that air-conditioning systems help the spread of the SARS-CoV-2 infection in office and indoor places (Chirico et al., 2020).

Another study by Li and colleagues, various health care center wards were prepared using heating, ventilation and air conditioning (HVAC) systems (Li et al., 2020). A research reported no strong evidence to support the association between COVID-19 air-bore transmission and HVAC systems (Belingeri et al., 2020). Wells–Riley equation contains the major contribution of ventilation:

$$P = \frac{nI}{nS} = 1 - \exp\left(-\frac{q\Gamma ts}{Q}\right) \quad (2)$$

where nI is the expected frequency of patients at room, nS is the frequency of susceptible at room at ts , nE is the number of spreaders 'quanta' (to the mean viral load necessary for infection transmission) at a rate γ_i (giving the total emission rate $\Gamma = \sum_{i=1}^{nE} \gamma_i$), q is the time-average volume flux of exhaled air per person and Q is the volume flux of fresh (clean) air entering the room (Bhagat et al., 2020).

Indoor Air Relative humidity (RH)

According to the evidence, in health care centers, RH is a major contribution for preventing contagious diseases, as it affects both growth and transfer of airborne of contagious agents (Azuma et al., 2020; Fadaei, 2014). RH affects the transmission of contagious agents. Suitable RH affects the survivability of: Viruses with lipid envelopes (i.e., *Influenza*

virus, Para-Influenza virus, Corona virus, and Varicella zoster virus lower RH (20%-30%RH); (b) Viruses non-lipid enveloped (i.e. Adenovirus, Enterovirus, and Rhinoviruses higher RH70%-90% RH); (c) Gram-negative bacteria (i.e. *Serratia marcescens*, *Klebsiella*, and *Proteus vulgaris* lower RH (<50% RH): and (d) Airborne gram-positive (i.e. *Staphylococcus epidermidis*, *Streptococcus haemolyticus*, *Bacillus subtilis*, and *Streptococcus pneumonia* bacteria lower RH (<50% RH) (Ahmadi and Fadaei, 2021; Shajahan et al., 2019). Nevertheless, it's well-proved that low RH (<20%) affects susceptibility to various contagious agents (Dietz et al., 2019). On the other hand, the low RH negatively affects the ability of the immune system's to cope with microorganisms (Ahlawat et al., 2020). Another study by Ahlawat reported that close areas with in dry conditions (humidity (< 40%), there is high probability of COVID-19 transmission (Ahlawat et al. 2020). Another study suggested an RH of 30-60% for healthcare settings (Balaras et al., 2007). One study reported a negative association between RH (increased from 23.33 to 82.67%) and COVID-19 transmission (Yao et al., 2020). Biktasheva mentioned that humidity affects COVID-19 transmission (Biktasheva, 2020). Another study by Huang et al., reported, in conditions with low indoor temperature and high environment temperature, there is a correlation between RH and outdoor absolute humidity (AH), which translates into increased COVID-19 transmission (Huang et al., 2020). One study explained that the viruses survived well at RHs below 33% and at 100%, whereas, at the intermediate RHs the viability was noticeably reduced (Lin and Marr, 2019). therefore, it is very important to set a minimum relative humidity standard for indoor places such as hospitals, offices, clinics, health care settings, populated areas, restaurants, and public transports for minimization of airborne spread of COVID-19.

Indoor Air Temperature

It has a crucial impact on patients' perception from thermal comfort. In other words, uncomfortable temperatures negatively affect the patients' satisfaction, like wakefulness and nervousness, and may result in shaking, inattention, and muscular and joint constriction (Shajahan et al., 2019).

Several studies reported creating thermal zones to met various needs of infected cases, and their separate thermal preferences such as: Operating room 24-26°C (74.2-78.8°F), Delivery room \geq 26°C (78.8°F), Nursery (for infants), around 28°C (82.4°F), Patient room 21-24°C (70-75°F), and Bronchoscopy 20-23°C (68-73°F) (Lyon and Freer, 2011). At first days of COVID-19 emergence, the severity of the disease was higher in countries with relatively lower environmental temperature (Hassan et al., 2020). One research explained that a considerable negative relationship among temperature and outbreak (Hassan et al., 2020).

Thus, based on recommends of CDC, WHO, and other studies effective ventilation is of crucial importance for control strategies developed for transmission of respiratory diseases, specially COVID-19 (Chinn and Sehulster, 2003; Fadaei, 2021; Wold Health Organization, 2020b). There are many researches about temperature and humidity such as: temperature should range from 17 to 28°C, and the RH should be 40 to 70% (Guo et al., 2020), the best humidity should range from 40 to 60% at workplace and a general indoor temperature

of 21–23°C (Guo et al., 2020). In a study by Turki et al. (2021) in the optimum indoor meteorological status such as temperature 23°C, relative humidity 53%, without sunlight, the aerosolized SARS-CoV-2 may stay infectious for up to 16 h (Habeebullah et al., 2021). Some studies say that COVID-19 deactivation is best at around 50-80°C and 40-50% relative humidity (Rezaei et al., 2020). All of these relevant research agrees with the results of the current study.

CONCLUSION

There is well-established evidence to propose that the temperature, relative humidity, and ventilation and air conditioning systems (ACSS), have beneficial effects to prevent COVID-19 infection. Caution should be taken when setting temperature and relative humidity, using a step-by-step process. The findings propose greatly that rather than natural ventilation (e.g., windows), use of artificial ventilation and ACSS may cause better IAQ in health-care centers and close places and reducing bioaerosols and PM exposure in the indoor air of health-care centers and close places.

Researchers, health decision-makers, policy-makers, to reduce the risk of vulnerability of people to future epidemics and pandemics, can act on six factors basic strategy of control COVID-19 include: hand hygiene, social distancing, screening and case finding, isolation and separating, decontamination and disinfection, and effective ventilation. Items aforementioned will more protect healthcare staffs, patients and the general popular. Our Results confirm that improving ventilation of populated places and hospitals will dilute and get out potentially infectious aerosols. More study and investigation are necessary to investigate the role of outdoor and indoor air quality management, particularly ventilation. Hence, to find whether ventilation systems can decline the spread of COVID-19, which requires more extensive research.

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