REVIEW

Can ventilation in healthcare facilities prevention of infection COVID-19?

Abdolmajid Fadaei

Department of Environmental Health Engineering, School of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran

Correspondence to: Abdolmajid Fadaei, Department of Environmental Health Engineering, School of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran; E-mail: ali2fadae@yahoo.com

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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. The prevention of air pollutants (*i.e.*, biological, particles, chemicals, and smoke) at the resource has the highest efficiency to keep safe air. 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? We systematically searched Embase, PubMed/MEDLINE, Scopus, PubMed Central (PMC), Google Scholar databases as well as medRxiv by using the following key-words: 'COVID-19', 'healthcare settings', 'prevention', 'ventilation', 'Hospital, 'Infection', and 'Air changes per hour. A total of 26 eligible articles were identified. The literature denotes that temperature, relative humidity, and ventilation and air conditioning systems have beneficial effects to prevent COVID-19 infection. 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: corona viruses infections, prevention and control, ventilation

1 Introduction

Initially, COVID-19 that begun at the end of 2019 has turned into a pandemic [1]. 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 [2, 3]. 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 [4], 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), CO_2, and bioaerosols agents in IAQ [5]. There are several parameters, such as origins, building construction and materials, air conditioning and its speed, inhabitant practice and functions that influence the IAQ [6]. 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) [7], for example, as the virus has a lipid envelope, its survival is longer in areas with lower ($<$ 50%) relative humidity (RH) than RH >80% [4]. 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.

2 Methods

Following a systematic review design, this research was conducted to evaluate can ventilation in healthcare facilities prevention of infection COVID-19? In total 25 articles were found to be eligible for a full evaluation ,then focuses on ten (N= 10) studies. We systematically searched 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. The quality of identified articles was evaluated using the PRISMA Preferred Reporting Items for Systematic Reviews and Meta-analyzes [8]. 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 CO_2 concentration. In this study used to air changes per hour, volumetric airflow per person, percent outdoor air intake, and CO_2 concentration methods.

Air changes per hour one significant change relates to the ventilation recommendations for patient rooms, values were estimated as follows [9]:

$$\mathrm{t_2 - t_1 = -\left[\ln\left(C_2/C_1\right)/(Q/V)\right] \times 60} \tag{1}$$

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 – (removal efficiency/100);
Q = air flow rate in cubic feet/hour;
V = room volume in cubic feet;
Q/V = 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.

3 Results

Of the 10 articles, 60% (4), 20% (2), and 20% (2) were based on the simulation, experimental, and observational methods, respectively (see Figure 1). These articles were from health care/hospital (4), public buildings (3), Residential places (1), dormitory (1) , and offices (1). The main results are provided in Table 1. 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 air changes/hour and outline of ventilation according to guidelines and standards of CDC and those published for controlling infection at healthcare settings. (see Table 2 and 3)

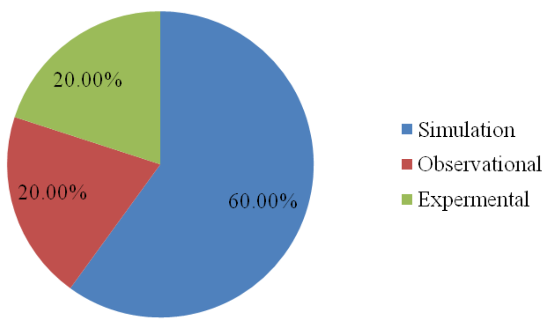

Figure 1 Condition type of design researches

Table 1 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.	[28]
Simulation	Public buildings	There is a major and firm possibility of airborne spread of COVID-19 in indoor air ambient	[38]
Simulation	Hospitals	Ventilation has a major impact on SARS-CoV-2 spread	[39]
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	[5]
Simulation	Patient Rooms	Increase ventilation rates were not causes reduce aerosol concentrations	[40]
Experimental	Hospitals	The few COVID-19 studies did not provide adequate indication that the virus may be spread by HVAC systems.	[3]
Observational	Dormitory	CO_2 mean level was 1230 $\pm$ 408 ppm and 1492 $\pm$ 837 ppm in the two dormitory buildings.	[41]
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	[42]
Observational	Health care centers	Simple changes in hospital structure noticeably enhanced natural ventilation, and seriously decreased air borne infection risk at little cost	[43]
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	[44]

Table 2 Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency [36]

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 3 Outline of ventilation characteristics in chosen areas of health-care centers [36]

Characteristics	All room (includes bronchoscopy suites)	Protective environment	Critical care room	Isolation anteroom	Operating room
Air pressure	Negative	Positive	Positive, negative, or neutral	Positive or negative	Positive
Room air changes	$\geq$ 6 ACH (for existing rooms); $\geq$ 12 ACH (fore novation or new construction)	$\geq$ 12 ACH	$\geq$ 6ACH	$\geq$ 10 ACH	$\geq$ 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 μm 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

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4 Discussion

4.1 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 [10].

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 $\geq$ 2.5 Pa to gurantee air flows from the corridor into the rooms designed for hospitalizing patients [9, 11]. Ventilation (>6 ACH) can guarantee both negative pressure difference (> 2.5 Pa) and airflow difference (> 56 L/s) (Table 2) [12, 13]. Upgrading ventilation of health care centers will dilution and removal potentially infectious aerosols [14]. Inappropriate use of ventilation systems has severe negative effects on transmission of COVID-19 [15]. Effective ventilation is a major technique to prevent expansion of contagious disease [16].

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 [17]. Masoumbeigi and colleagues mentioned that mechanical air conditioning and natural ventilation are available methods that can be used for air cleaning in hospitals [18]. Masoumbeigi and colleagues and Faridi and colleagues illustrated that ventilation (either mechanical or natural) were applied in healthcare facilities [18, 19]. Another study by Li and colleagues, various health care center wards were prepared using heating, ventilation and air conditioning (HVAC) systems [20]. A research reported no strong evidence to support the association between COVID-19 air-bore transmission and HVAC systems [21]. Wells–Riley equation contains the major contribution of ventilation:

$$\mathrm{P} = \frac{nl}{n\mathrm{S}} = 1 - \exp\left(-\frac{q\Gamma ts}{Q}\right) \tag{2}$$

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 γi (giving the total emission rate $\Gamma = \sum_{i=1}^{nE} \gamma_i$), q is the time-average volume fluxof exhaled air per person and *Q* is the volume flux of fresh (clean) air entering the room [22].

4.2 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 [23, 24]. RH affects the transmission of contagious agents. Suitable RH affects the survivability of: Viruses with lipid envelops (*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) [25, 26]. Nevertheless, it's well-proved that low RH (< 20%) affects susceptibility to various contagious agents [27].

On the other hand, the low RH negatively affects the ability of the immune system's to cope with microorganisms [28].

Another study by Ahlawat reported that close areas with in dry conditions (humidity (< 40%), there is high probability of COVID-19 trransmission [28]. Another study suggested an RH of 30-60% for healthcare settings [29]. One study reported a negative association between RH (increased from 23.33 to 82.67%) and COVID-19 transmission [30]. Biktasheva mentioned that humidity affects COVID-19 transmission [31]. 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 [32].

4.3 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 [26].

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), around28°C (82.4°F), Patient room 21-24°C (70-75°F), and Bronchoscopy 20-23°C (68-73°F) [33]. At first days of COVID-19 emergence, the severity of the disease was higher in countries with relatively lower environmental temperature [34]. One research explained that a considerable negative relationship among temperature and outbreak [34].

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 [9, 35, 36]. 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% [37], the best humidity should range from 40 to 60% at workplace and a general indoor temperature of 21–23°C [37]. All of these relevant research agrees with the results of the current study.

5 Conclusion

There are 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.

Availability of data

All data generated or analyzed during this study are included within the Article.

Conflict of interests

The author declares no conflict of interests.

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