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Review article

Indoor Air Quality Strategies for Air-Conditioning and Ventilation Systems with the Spread of the Global Coronavirus (COVID-19) Epidemic: Improvements and Recommendations

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ABSTRACT

The coronavirus has come to the world and spread with great wide among the countries of the world and has resulted in numerous infections that exceeded 167,181,023 million patients and are close to 3.5 deaths by September 2021. It also brought with it panic and fear, halted many activities, and led to the decline of the global economy. It changed human behavior and forced people to change their lifestyles to avoid infection. One of the most sectors that must be taken into consideration through pandemic coronavirus (COVID-19) around the globe is the air conditioning systems. The HVAC systems depend on the air as a heat transfer medium. The air contains a group of pollutants, viruses, and bacteria, and it affects and destroys human life. The air filter plays a major role as an important component in the air conditioning systems. Thus, it requires more effort by researchers to improve its design to prevent the ultra-size of particles loaded with coronavirus (COVID-19). This paper provides insight into the design of existing combined air-conditioners on their suitability and their impact on the spread of the hybrid coronavirus epidemic and review efforts to obtain a highly efficient air filter to get rid of super-sized particles for protection against epidemic infection. In addition, important guideline recommendations have been made to limit the spread of the COVID-19 virus and to obtain indoor air quality in air-conditioned places.

1. Introduction

Recently, the World Health Organization stated that COVID-19 is a global epidemic on March 11, 2020, after its spread and outbreak in late 2019 from Wuhan, China. Therefore, the World Health Organization has announced the highest level of global readiness and has imposed challenges and restrictions as a result of threats and risks to deny the transmission of COVID-19 infection. The sources and reasons for spreading the COVID-19 virus varied, and to date, the definite reasons for transmitting and spreading the virus have not been identified. The rapid spread of the Coronavirus has led to the suspension of many industrial, commercial, and agricultural activities, and to many investment activities, which led to the deterioration of the global economy. Coronavirus (COVID -19) was first detected in China in Wuhan province at the end of 2019, and the COVID-19 pandemic was announced on January 30, 2020 (The National Health Commi, 2020). Then the epidemic appeared in the countries of the world quickly and

frighteningly and created with it a global health crisis and led to severe confusion and prevention of many aspects of life, which struck the global economy. Fig. 1 presents the distribution of COVID-19 confirmed cases globally.

On February 18, the National Health Committee of the People's Republic of China formally announced some guidelines for dealing with the corona pandemic as the epidemic outbreak center for COVID-19, which originated from Wuhan industrial city because of their awareness and understanding of the stages of development and transmission of the global epidemic (Wang and Du, 1971). Although the situation has improved in some countries around the world, the World Health Organization (WHO) has recently issued warnings that the current situation will worsen at the global level. It has become one of the most serious public health threats to humanity in world history. To date, there is no treatment, drug, or vaccine to stop the spread of COVID-19. Therefore, it is possible to adhere to preventive measures such as social distancing, quarantine, and hand washing, especially in outdoor environments that carry the virus, and to correct air-conditioning and ventilation systems

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Nomenclature			
AHU	Air handling unit	IAV	Influenza A virus
ASHRAE	American society of heating, refrigeration, and air conditioning engineers	IPA	Isopropyl alcohol
AT	Ambient temperature	MERV	Minimum efficiency reporting value
CDC	Center of disease control and prevention	OSHA	Occupational safety and health administration
DOAS	Direct outdoor air supply units	PEF	Peak expiratory flow
EEAF	Enhanced electrostatic air filters	PM	Particle matter
EEPF	Enhanced electrostatic pleated filter	PRRSV	Porcine reproductive and respiratory syndrome virus
ERV	Energy recovery ventilation	PS	Population size
ERW	Energy recovery wheels	REHVA	Federation of European heating, ventilation, and air conditioning associations
HRV	Heat recovery ventilation	SBS	Sick building syndrome
HIV	Human immunodeficiency virus	SNAF	Silk nanofibrous air filter
HVAC	Heating, ventilation, and air conditioning	TVOC	Total volatile organic compound
HEPA	High-efficiency particulate air	UVGI	Ultraviolet germicidal irradiation
IAQ	Indoor air quality	VOCs	Volatile organic compounds
		WHO	World health organization

installed in air-conditioned locations to ensure that the virus does not spread through the air (AmoateyHamid et al., 2020; AliOmar and Alharbi, 2020a). The most important guidelines illustrated that atmospheric aerosol holds dispersed solid or liquid particles which are suspended in the air in a relatively closed environment. Referring to the World Health Organization statistical data, 4.6 million people die annually from diseases directly related to poor air quality (Cohen et al., 2017). Therefore, poor air quality is responsible for increasing the number of deaths every year (European Environment Agen, 2005). Air contains particles and is in the form of industrial dust particles, dust particles, car emission particles, bacteria, microorganisms (viruses), and other suspended pollutants. When a person is infected with an epidemic virus, coughing, sneezing, breathing forcefully, or speaking out loud, droplets of saliva will be excreted by infected people as a result of sneezing, coughing, or speaking, and the spray particle size will be 1–5 mm spread in a space of about 1–2 m (Yu et al., 2004). The aerosol is scattered by infected droplets via infected patients and become the bio-aerosols, which become the vector of the epidemic (Adhikari et al., 2019). The particles in a bio-aerosol are generally 0.3–100 µm in diameter; nevertheless, the respirable size fraction of 1–10 µm is of primary concern (Tindale et al., 2020). However, the aerosol can travel hundreds of meters or more which can carry and transfer viruses (Kulkarni et al., 2016). In Italy, large numbers of infected people appeared in Europe, and the epidemic spread to all regions of the world (ConciciniBruno and Caro, 2020). Fig. 2 shows the prevalence of COVID-19 on September 3, 2020 (data collected by the European Center of Disease Control and Prevention) (Bontempia et al., 2020a; AliOmar and Alharbi, 2020b; Morawskaa and Cao, 2020; Barcelo, 2020).

Coronavirus particles appear as a spherical shape with an average diameter of approximately 120–160 µm and typically decorated by a

surface with an average of 20 µm. The particles of the coronavirus (COVID-19) take the form of club or petal-shaped surface projections (peplomers or spikes). The coronavirus particles appear by an electron micrograph resembling infected tissues as a solar corona, as demonstrated in Fig. 3.

Coronavirus has an average diameter of about 0.12 µm, and it confirms the idea behind a mask N95, its ability to protect humans, and filtering strength down to 0.1 µm with an efficiency of 95% down to the size of COVID-19. Fig. 4 illustrates the size of coronavirus compared to others.

Research studies estimate that SARS-CoV-2 remains viable in the air for hours and varies according to the air temperature and humidity and on surfaces for several days, as the average lifespan of the coronavirus, as aerosolized particles, is about an hour. Laboratory vitro testing has shown that SARS-CoV-2 lasts for up to 72 h on plastic and stainless steel, while it lasts for 24 h on cardboard, and for copper, it lasts for up to 4 h (Bontempia et al., 2020b). Estimates indicate that the sequence interval for COVID-19 is 4–6 days near or shorter than the average incubation period of the epidemic virus by 95% and confirms that a large percentage of secondary transmission may occur before the onset of the disease and its symptoms (Nishiura et al., 2020). A few studies have handled the relationship between ventilation and health (Sundell, 2004). The European multidisciplinary scientific review group has found 30 scientific studies to be conclusive directly on this issue (Wargocki et al., 2002). Scientific evidence indicates that the rates of ventilation (outdoor air) are less than 25 l/s/p in commercial and institutional applications which are associated with increased SBS risk, increased short-term sick leave, and hence lower productivity (Mishra and Ramgopal, 2015; MujanAleksandar, 2019). The relationship between health effects and ventilation rates in homes is rather rare.

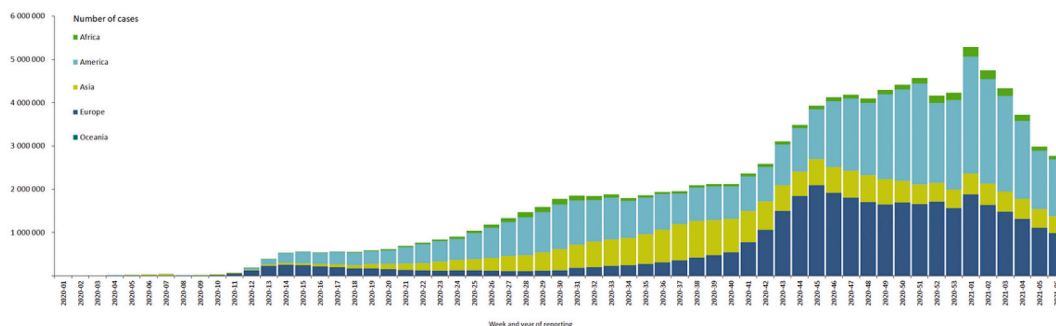
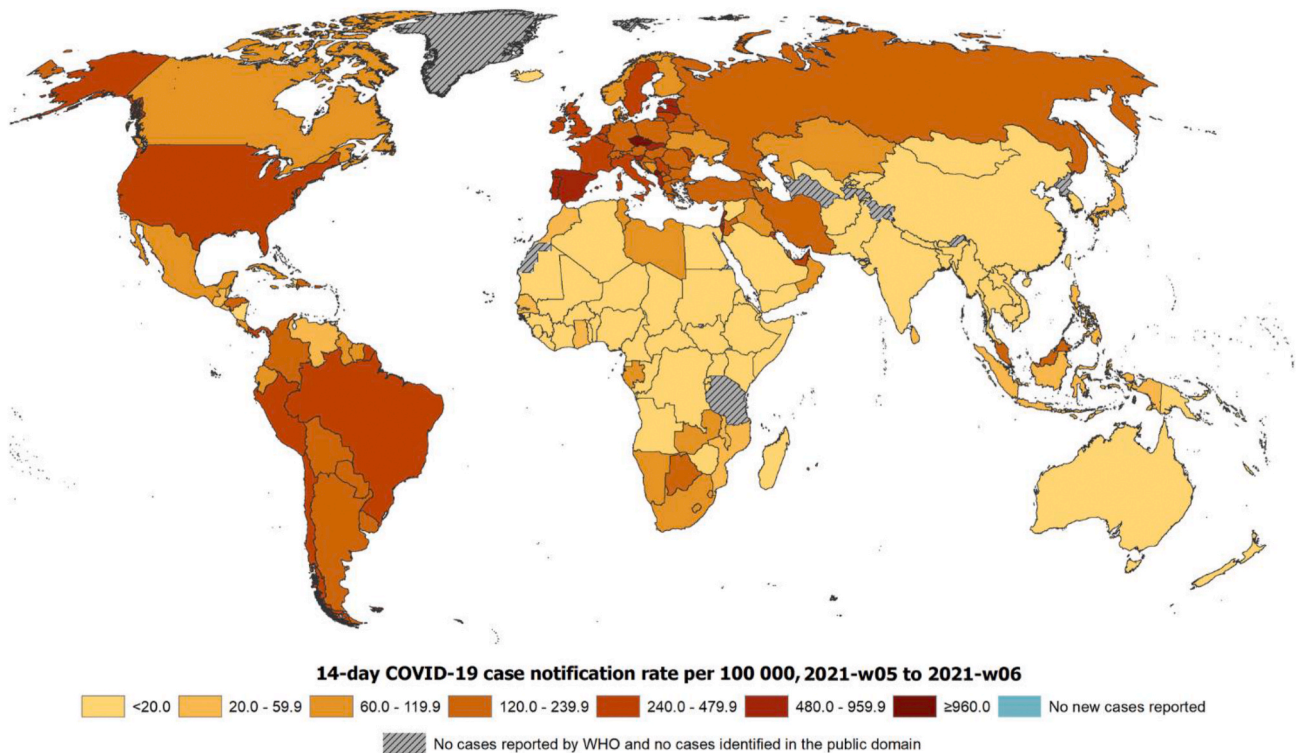


Fig. 1. COVID-19 confirmed cases distribution by continent, as of week 6, 2021.



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Fig. 2. Prevalence map of COVID-19 on February 18, 2021 (CDC).

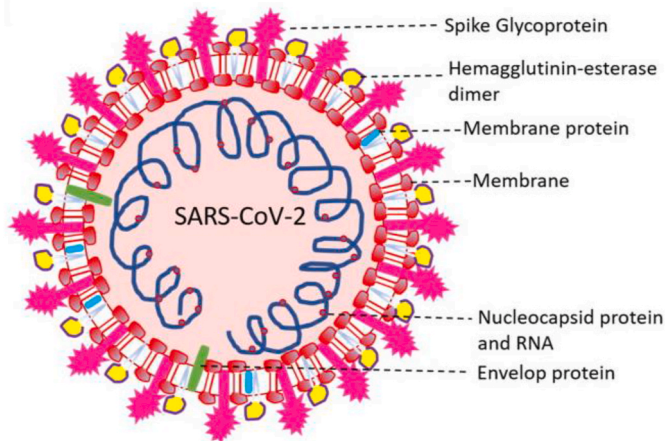


Fig. 3. Coronavirus structure (COVID-19) (Boopathi et al., 2020).

However, the insufficient ventilation rate in homes formed a greater risk factor for health effects (coughing, wheezing, asthma, and airway infections) (Wai Tham, 2016) which reduced ventilation rates in homes to conserve energy in Nordic countries and western countries which have had the greatest impact on the healthy life of citizens. No one denies the importance of air to the human body. An adult human body needs a normal breathing rate of 2.5 L of air or more (Bakó-Biró et al., 2012). After exhalation, about 0.5 L of air remains in the lungs and airways which depend on age. Newborn breathing rate ranges from 40 to 45 inhalations/exhalations per minute, for the child from 25 to 30 inhalations/exhalations per minute, and for an adult from 16 to 20

inhalations/exhalations per minute. Table 1 explores the breathing rate for inhalation and exhalation of a person.

From the above, several emergency factors in society make IAQ a priority that must be taken care of and addressed (Melikov, 2016) which is to push the economy up, urban growth, increase population densities, energy efficiency, high air conditioning and climate changes, the production of new materials and products, and epidemic viruses and their rate of rapid spread as happened with COVID-19. These important factors present the extent of exposure to indoor air pollutants and their effect on health. Heating, ventilation, and air conditioning (HVAC) system design plays an important role in achieving optimum air quality and optimum comfort, but the process of transporting outside air through air conditioning systems and their treatment with fine filters does not necessarily have 100% efficiency. Therefore, there is a possibility that some microscopic particles can escape in the treated air and carry the COVID-19 viruses that cause infection to the population. This requires reviewing the cycle and path of these devices and designing their components to ensure clean and free air from viruses. Air conditioning systems include important components that may help transmit viruses and need to be revised, such as air handling units, filters, transmission channels, and fans. This is called air quality as balance must be achieved between thermal comfort and air quality in healthcare facilities to improve IAQ. This paper spots and discusses the current status to set the factors that affect the indoor air quality and assess its effects in the light of the corona global pandemic (COVID-19) on the efficacy of solutions through the use of appropriate air filters; moreover, the study comprises an assessment of the current status of the air conditioning devices, determining the future requirements and expectations, and the challenges that must be re-corrected and their compatibility with the emerging pandemic. The importance of air

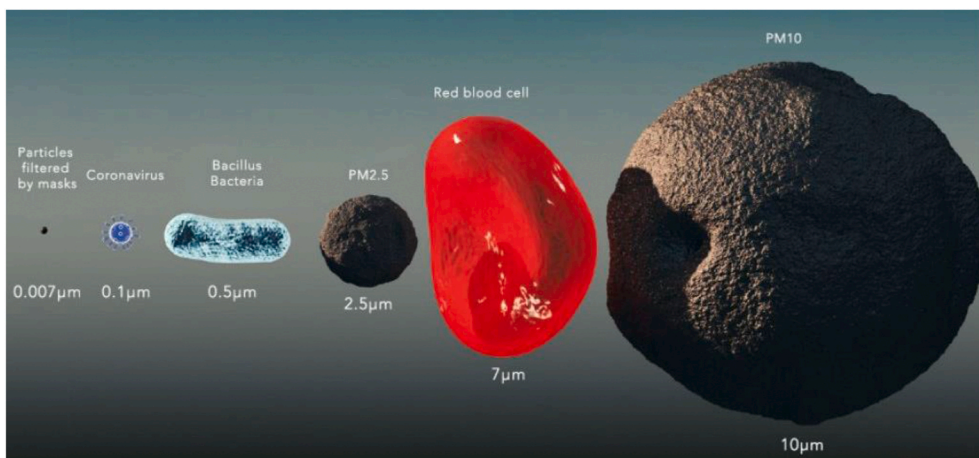


Fig. 4. The volume of coronavirus with others (<https://abcdust.net/how-1>).

Table 1

Level of human inhaled and exhaled air components for healthy adults (Voigt and Pelikan, 2010).

Element	Inhaled air (%)	Exhaled air (%)
Oxygen	20.96	15.4–17
Nitrogen	78	78
Carbon dioxide	0.04	4–5.6
Water vapor and other gases	1	1

conditioners of various types is evident in many applications (Mimi Elsaid, 2020), especially hospitals, and the importance of studying the topic from different dimensions in light of the spread of the coronavirus global pandemic has become an imperative. Besides, the present research is related to the investigation by reviewing the previous literature to assess the impact of important elements that group factors as variables with the prevalence and death rate of the global epidemic of coronavirus and its relationship to air conditioners and air filters. These factors are the effect of air pollution on the prevalence of the number of people infected with the epidemic of coronavirus, the effect of airborne particles as a vector for infection with COVID-19, and the effect of climatic conditions of medium-temperature and humidity on the prevalence of those affected by the global epidemic. The research also, for the first time, highlights the evaluation of the mechanisms and current air-conditioning systems and their relationship to the global pandemic prevalence rate; moreover, it suggests methods to correct their positions to reduce the pandemic spread and focus on the quality of air filters which are suitable to limit the spread of the pandemic in isolation rooms, hospitals, and other applications.

2. Air as a carrier of coronavirus

Given the difference in views regarding whether the air is the carrier of the global epidemic of coronavirus or not; therefore, it is an important reference point in the review and investigation through the literature published in this regard and a study of the impact of thermal conditions, such as air temperature, air speed and air humidity, which are some of the objectives of air conditioning devices, on the rate of global COVID-19 epidemic spread. Fig. 5 illustrates the schematic diagram of the COVID-19 (60–140 nm) linked with a larger carrier that is airborne to form a 100–300 nm aerosol (Zhu et al., 2020).

The advisory Indian Society of Anesthesiologists (ISA) issued an article announcing the highest priority of the strictly enforced requirements to isolate those infected with the epidemic coronavirus, in which it was stated that the airborne infection through the air surrounding a healthy person transmits the infection (Global Burden of

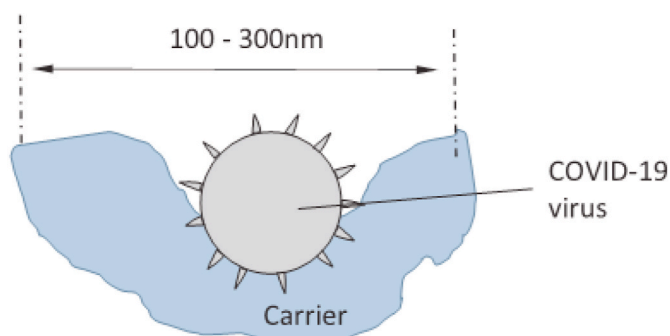


Fig. 5. Coronavirus with a larger carrier as airborne.

Disease Collaborative Network, 2018). Malhotra et al. (2020) confirmed that one of the COVID-19 ways of infection transmittal is aerosol droplets in the air by people infected with COVID-19. The US centers for disease control and prevention (Liew et al., 2020) recommended that airborne infection isolation rooms be separated only for COVID-19 patients subjected to aerosol generation procedures. These isolation rooms must be negative pressure zones to prevent microorganisms from escaping into the corridors and then transmitting the infection to all. Centers for Disease Contr (2019) reported the observation of the medical team accompanying the plane via a Boeing 737, regional jet, Learjet 35 during the transfer of American citizens from Wuhan-China, to evacuate them and secure their exit from the source of the global epidemic. After examining all American passengers and separating those confirmed to be infected with the virus, it is safe for people. However, within a short period of time, it was found that others were infected despite the procedures of separation and tight quarantine. At that time, they announced that the air is a carrier of the virus and that the epidemic has spread to healthy individuals through the air-conditioned air that carries the virus from infectious people.

After the SARS outbreak in Hong Kong (Brian Cornelius et al., 2020), the United Christian hospital transformed a hospital with a positive pressure role into a negative pressure for patients with airborne viral infections; accordingly, the number of patients infected with SARS was reduced. Likewise, in Singapore during the SARS epidemic (TanMBChB et al., 2020), patient rooms were converted to a negative pressure by attaching exhaust fans to highly efficient micro-air filters with windows. Indeed, the experiment succeeded in reducing the spread of the airborne epidemic and using highly efficient particulate air filters to remove 99% of the fine air material because the rate of the air change is approximately 25 times an hour (Phoon et al., 2019). Gralton et al. (2011)

codified the environmental geographic determinants of the accelerated spread of COVID-19 that generate a high level of infection and mortality and proposed a strategy to deal with the epidemiological threats of viral infection. The statistical study was conducted at the level of 55 Italian provinces until the date of April 7, 2020. The results revealed that the rapid and widespread of COVID-19 in northern Italy has a high relationship to cities with air pollution measured days exceeding the limits specified for PM₁₀ or ozone. Additionally, cities with air pollution greater than 100 days with PM₁₀ have a very high average of 300% of people with a viral infection. COVID-19 axial dynamics is mainly due to the mechanism of air pollution and its transmission to humans via airborne viral infection through the infected spray and adapted or mechanical ventilation sources and its transmission from one person to another. The dynamics of viral infections, such as COVID-19, are due to the complex interaction between air pollution, meteorological conditions, biological characteristics of viral infections, and the health level of individuals (habits, immune system, age, gender, etc.).

3. Air pollution as an influence on the spread of the coronavirus

The World Health Organization has announced the thirteenth cause of premature deaths worldwide. Outdoor and indoor air pollution contributes to increasing the number of premature deaths around the world by 4.9 Million deaths annually (Coccia, 2020) as depicted in Fig. 6.

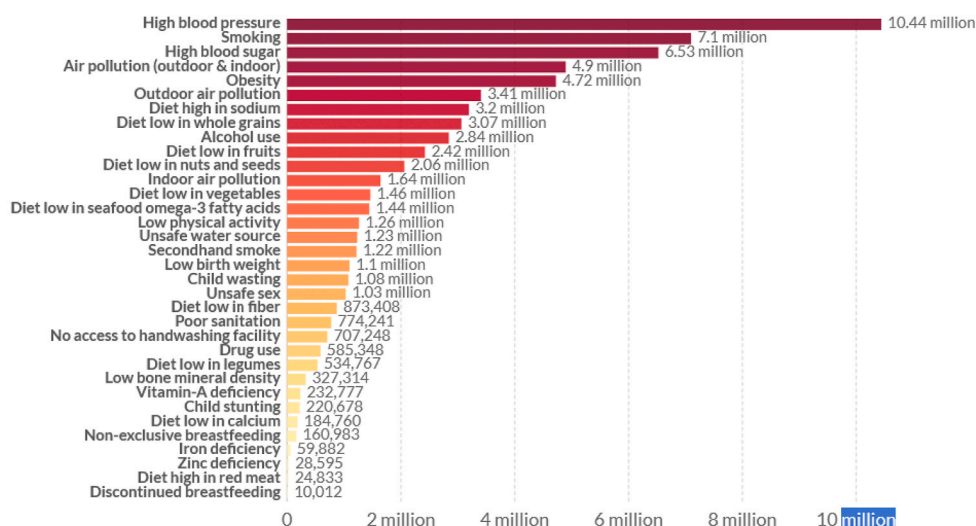
The effect of air pollution as a dangerous factor has long-lasting effects on increasing the global disease burdened by about 147.42 million citizens. This confirms that a person lives well-estimated years of life but in poor health. Fig. 7 illustrates that air pollution is at the top of the list, making it one of the main risk factors for poor health and affecting their lives worldwide (Jonathan et al., 2012).

Therefore, the effect of air pollution has become a global problem and includes developed countries, such as European countries where 193,000 people died in 2012 from airborne particles (Ortiz et al., 2017). Air pollution-related deaths occur due to acute asthma, bronchitis, emphysema, lung and heart disease, and respiratory allergies (Brauer, 2010). The results presented by Dantas et al. (2020) showed the effect of partial closure on the air quality of Rio de Janeiro. The main restrictions were applied as of March 23 and followed in April through reducing social isolation as partial population counts, reduced road traffic, and reduced economic activity led to lower levels of carbon dioxide and nitrogen oxide, and on the contrary led to increased ozone concentrations as the particles Ozone is, in general, a pollutant of primary concern in Rio de Janeiro. These results indicate that an evaluation of the city's

air quality policies requires analysis of air masses transported from industrial areas as well as a study of the specifications of volatile organic compounds and the effect of NMHC/nitrogen oxides ratios on ozone levels, bearing in mind that high temperatures and solar radiation indices prefer the formation of ozone. Therefore, the influence of meteorological conditions cannot be ignored and must be examined in the future. Tobías et al. (2020) reported the changes in air pollution levels through the lock procedures in Barcelona (northeastern Spain) from March 14, for a period of two weeks after the beginning of the SARS-CoV-2 epidemic, by examining the time evolution of air pollutants and observing the indoor air quality. After two weeks of lock, urban air pollution was reduced with major variations among pollutants. PM₁₀ average concentrations decreased by -28% and -31% in the traffic and urban background stations, respectively. Table 2 presents the mean concentrations and variations of different air pollutants between February 16th to March 13th (before lock) and March 14th to March 30th (during the lock) in Barcelona, Spain.

It is noted from the data in the table that the air quality continued to improve the ratios of PM₁₀, PM_{2.5}, BC, and NO₂ during the closure process to the lowest levels due to the restrictions of movement of Spanish citizens and the closure of factories. This precautionary measure reduced air pollution and led to a unique opportunity to minimize the infected people of the HIV epidemic and is a significant indicator for evaluation. Through a review of previous research, it was found that several tests were carried out to improve the ambient air quality and an evaluation study of the impact of this to improve negative results accordingly (Burns et al., 2020). Cicala et al. (2020) examined the effect of partial closures and housekeeping measures as a result of the global corona epidemic on emissions and air pollution and, consequently, the impact on the health status of American citizens during the spring of 2020. Homestay policies have resulted in a 40% drop in travel and electricity consumption decreased by 6%. Based on the foregoing, the number of deaths due to air pollution decreased by 25%, and carbon dioxide emissions decreased by 19% over the same time frame, thus improving air quality through the indicator. Zhang et al. (2020a) collected the daily records of hospital attendants for respiratory disease treatment and inventory of air pollution and weather conditions in Shenzhen, China, during the same time period.

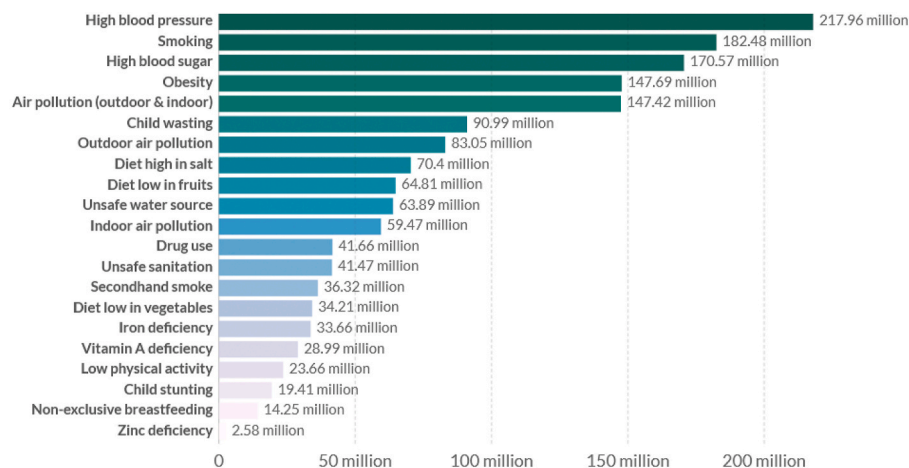
Hospitalization hazards linked with short-term exposure periods for PM₁ and PM_{2.5} were estimated. The concluding results manifested that exposure to air pollution with PM₁ and PM_{2.5} caused significant adverse effects on the hospitalization of respiratory diseases with increased admission of pneumonia and chronic obstructive pulmonary diseases,



Source: IHME, Global Burden of Disease (GBD)

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Fig. 6. Deaths around the worldwide annually of outdoor and indoor air pollution (Coccia, 2020).



Source: IHME, Global Burden of Disease

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Fig. 7. Impact of outdoor and indoor air pollution globally on health life annually (Coccia, 2020).

Table 2

Average concentrations and variations of air pollutants at different stations before and during lock in Barcelona, Spain (Tobías et al., 2020).

Type of station/air pollutant	Before lock	During lock	Variation	
			$\mu\text{g}/\text{m}^3$	(%)
Urban background				
PM ₁₀	22.4	16.2	-6.2	-27.8
BC	1.1	0.6	-0.5	-45.4
NO ₂	30.0	15.9	-14.1	-47.0
SO ₂	1.2	1.0	-0.2	-19.4
O ₃	52.4	67.3	+14.9	+28.5
Traffic				
PM ₁₀	29.2	20.2	-9.1	-31.0
NO ₂	42.4	20.6	-21.8	-51.4
SO ₂	2.5	2.6	+0.1	+1.8
O ₃	41.8	65.9	24.1	+57.7

but no effects were shown on asthma and upper respiratory infection. Statistical data by reviewing the conditions surrounding the deceased as a result of the epidemic of COVID-19 in the United States of America displayed that the risk of death increases with long exposure to air pollution. Wu et al. (2020a) investigated long-term exposure to fine particulate matter (PM_{2.5}) and its correlation with increased risk of death of COVID-19 from data available in 3000 provinces in the United States of America, representing 98% of citizens as of April 22, 2020. The following factors were taken into consideration: population size, age distribution, population density, time since the start of the outbreak, time since the state issued the order to stay at home, hospital beds, number of individuals tested, weather, and social, economic, and behavioral variables such as obesity and smoking. The results approached that long-term exposure to a slight increase of only $1 \mu/\text{m}^3$ of PM_{2.5} leads to an 8% increase in COVID-19 mortality (95% confidence interval). The scientific paper confirms that the enforcement of current air pollution regulations to protect human health during and after the COVID-19 crisis is necessary and important to maintain the health of citizens which is confirmed by Wang et al. (2020) and Gautam (2020a). Han et al. (2020) outlined the impact of air pollution on the immune system of Chinese citizens by collecting the number of confirmed cases and deaths from Chinese national health as a result of the global epidemic and was used by 31 provinces in China from December 1, 2019 to March 20, 2020. Provincial air pollution and meteorology data were also collected from the China National Environmental monitoring center and the US national climate data, daily migration flows between cities and movements within the city (from Baidu), and demographic characteristics including age distribution, gender, education, and average

household income. On rates of chronic diseases and joint infections from relevant research articles. The results announced that the infection rate is increasing significantly in major cities all over the world, especially in industrial areas. The incidence of COVID-19 is related to the concentration of air pollution because it weakens the immune system. To reduce the incidence of infection globally, it is necessary to adhere to effective restrictions and plans to reduce air pollution (Sharma et al., 2020). The concluding results of Han et al. (2020) were also confirmed by articles Contini and Costabile (2020), Gautam (2020b), and Shehzad et al. (2020). The relationship between the COVID-19 outbreak measured by the number of infected cases and air pollution measured by PM_{2.5} was studied by -ashary Mozghan et al. (1041) at the level of 31 Iranian districts in 19 governorates during the period from February 2020 to March 11, 2020. The findings explored that air pollution has a positive impact and contributed to the spread of the COVID-19 epidemic in the districts of Iran, while its impact on the climate is unclear. The same conclusive findings were presented by Fattorini and Regoli (2020) applied in Italy on 71 Italian provinces. Chronic exposure to atmospheric contamination can represent a favorable context for the spread of the virus. Proinflammatory responses and a high incidence of respiratory and cardiac affections are well known.

4. Air temperature and humidity effect on coronavirus activity

Numerous studies have pointed to a direct relationship between climatic conditions and the prevalence of the viruses (Mecenas et al., 2020; Yuan et al., 2020). Previous research (Casanova et al., 2010a) has shown that above a relative humidity of 80% or lower than 20% most coronaviruses are still active after 2 day at a constant temperature of 20 °C. The virus is inactivated more rapidly at 40 °C than at 20 °C. At a constant temperature and relative humidity of 50%, less than 1% of the viruses survived after 2 days as seen in Fig. 8 (Casanova et al., 2010b).

Rising temperature, wind speed, and the overall increase in solar radiation have been shown to be potential climatic factors that gradually reduce the effects of the epidemic in Rio de Janeiro. Therefore, it can be considered in other tropical countries around the world (Rosario et al., 2020). Ma et al. (2020) aimed to explore the relationship between the prevalence of coronavirus (COVID-19) and weather parameters (temperature, humidity) by collecting statistical data for the period from January 20, 2020 to February 29, 2020 among Chinese citizens. The statistical results of the study showed that meteorological factors are important factors in influencing infectious diseases such as SARS and influenza. The temperature and air velocity also showed a positive relationship in the rate of virus spread, but negatively with absolute humidity. Their results indicate that it is reasonable to maintain a stable

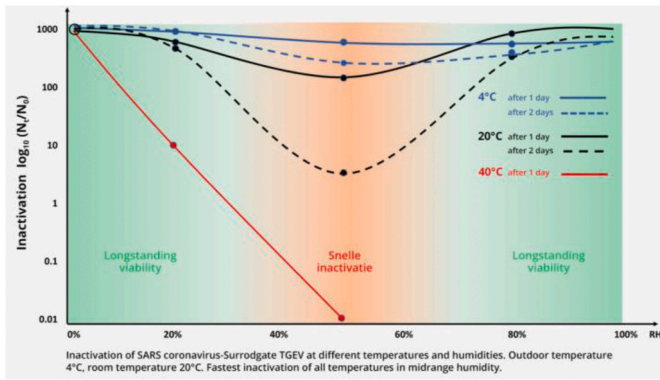


Fig. 8. Temperature and humidity effect on the spreading of coronavirus (Casanova et al., 2010b).

and comfortable environment for patients during treatment. Mehdi et al. (2020) conducted a study on the statistical data of the provinces of the state of Iran until April 10, 2020, when Iran announced the arrival of a number of people infected with coronavirus 68,192 cumulative cases of COVID-19, including 4232 deaths. The study relied on a set of factors such as the ambient temperature (AT) and the population size (PS) on the coronavirus transmission and survival rate as depicted in Fig. 9.

The characteristics of future coexistence were investigated using a mixing matrix. Data and results presented that the AT parameter had a linear relationship with the number of people with COVID-19 in different provinces of Iran and the coronavirus transmission rate. They do not have high sensitivity, so the number of COVID-19 cases in warmer climates is lower than those in mild or cold climate. Thus, it is recommended that cities/provinces with a population of more than 1.7 million people should have more stringent and more accurate controls. Iqbal et al. (2020) documented the relationship between the COVID-19 outbreak with the weather changes in Wuhan and its extensive impact on the Chinese economy. The study used the statistical data of the average daily temperature (hourly data) with weather data from the China Meteorological Administration, and the daily confirmed cases approved by the Chinese Ministry of Health for COVID-19. Data collected daily was processed using the Wavelength Conversion Coefficient (WTC), Partial Wavelet Coherence (PWC), and Wavelength Coherence (MWC) method from January 21, 2020 to March 31, 2020. The results revealed a possible effect of slowing the prevalence of infection during external temperature ranges above 21 °C which is the minimum and maximum temperature observed during the observation period and indicates that high temperature may help stop the spread of COVID-19. Wu et al. (2020b) presented the results of the effects of meteorological parameters such as relative humidity and temperature

on daily cases and deaths due to the dispersed COVID-19 disease as the biggest challenge facing the world. Daily data on 166 countries (excluding China) were collected on meteorological conditions of new cases and deaths by COVID-19 of March 27, 2020 as illustrated in Fig. 10. Linear generalized additions model was utilized with control of potential confounders and wind speeds taking into account the average age of the population, the health security index, human development index, and population density. The results manifested that the relative humidity and temperature are closely related to the prevalence rates of coronavirus globally and the virus can be partially suppressed by increasing temperature and humidity. A 1 °C temperature increase caused a 3.08% decrease in daily infected cases, while a 1% increase in relative humidity was associated with a 0.85% decrease in daily infected cases.

Bougherara and Benramache (2020) analyzed by comparison the cases of COVID-19 in nine African countries for the same climatic conditions due to their different geographical location on the equator from the rest of the world in their climate and environment. The results showed that the equator countries in Africa were not greatly affected by COVID-19 due to the tropical climate and therefore a few infections were recorded due to the high temperature. Marcos Felipe Falcão Sobr (2020) analyzed the associations between prevalence and deaths due to COVID-19 with meteorological variables such as mean minimum and maximum temperatures, precipitation from daily data in addition to COVID-19 and SARD infection data from December 1, 2019 to March 28, 2020 from meteorological weather stations around the world. Country population density and COVID-19 epidemic exposure time were monitored as control variables. Increase of temperature by 1 °F in the daily average led to minimizing the number of affected COVID-19 epidemic cases by about 6.4 cases/day. The results also displayed that there is a positive relationship between increasing the rate of rainfall and the increasing cases of epidemic COVID-19 per inch/average – there was an increment of 56.01 cases/day. Relative humidity (RH) and temperature are involved in the spread of coronavirus inside buildings, and thus on virus activity and the formation of droplet nuclei. To limit the transmission of some viruses in buildings, change the air temperatures and humidity levels. In the case of COVID-19, this can be done by adjusting the humidity to a high rate of 80% or above and a temperature around 30 °C in the air conditioner. However, these conditions of high humidity and high temperature are uncomfortable for humans and cause the growth of bacteria. COVID-19 was found to be very stable for 14 days at 4 °C; while it is stable for 1 day at 37 °C and for 30 min at 56 °C which is needed for deactivation (–19 guidance d, 2020). It is certain that humidity up to 65% may have a very limited effect or have no effect on the stability of COVID-19. Therefore, the evidence does not support that moderate humidity (RH 40–60%) will help reduce the susceptibility of SARS-CoV-2; hydration will not be achieved as a means to reduce the

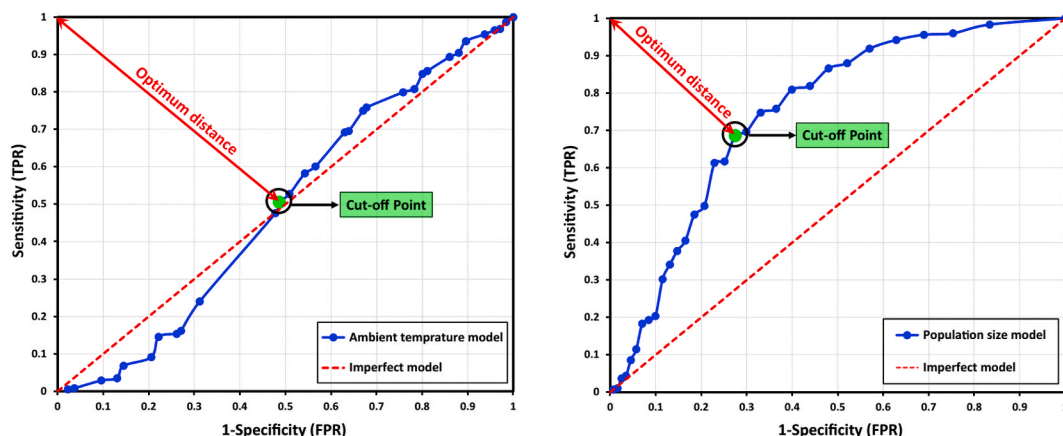


Fig. 9. Sensitivity analysis of COVID-19 spreading rate of (AT) and (PS) in different provinces of Iran (Mehdi et al., 2020).

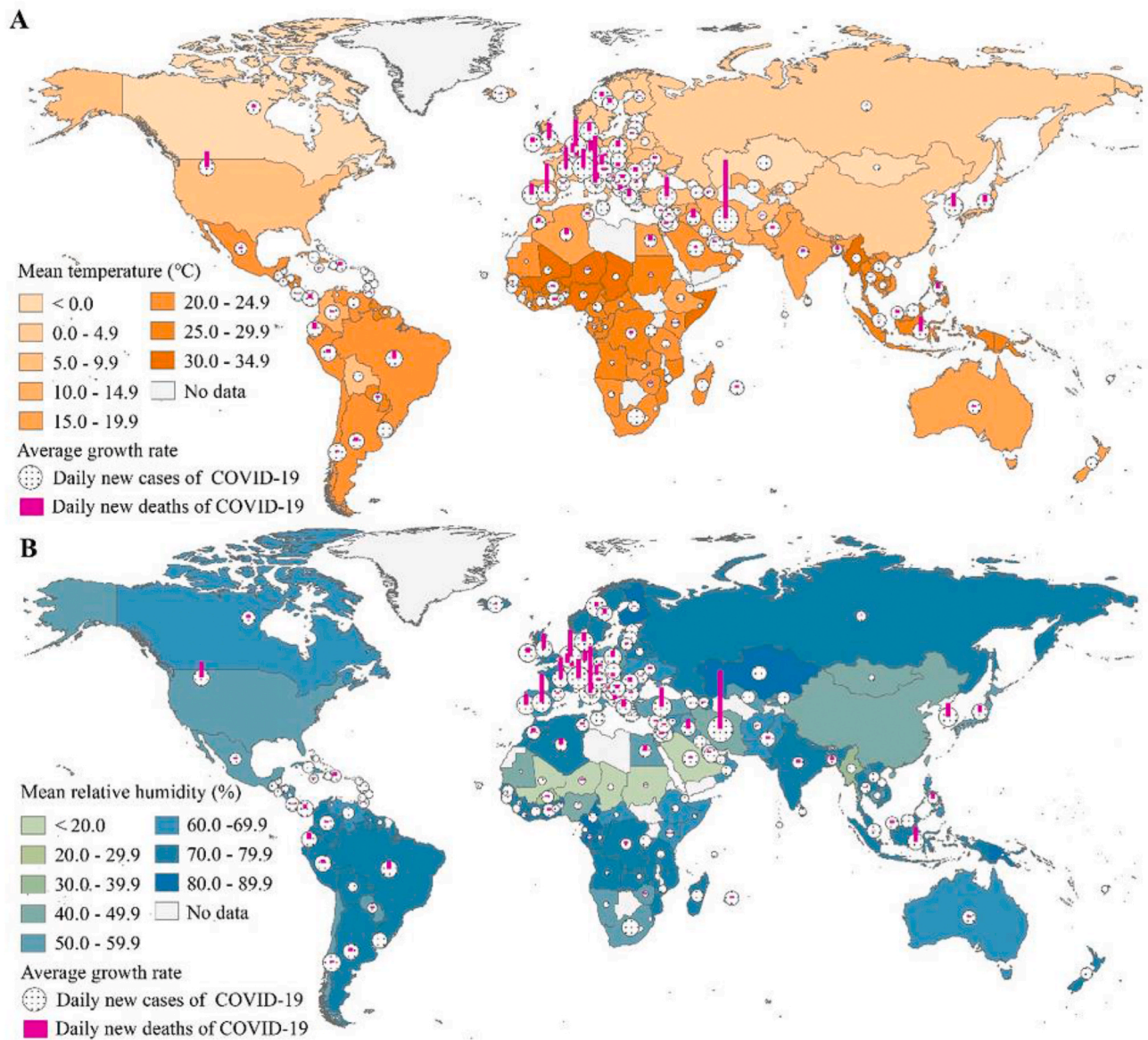


Fig. 10. Distribution of mean relative humidity and mean temperature with the average growth rate of daily infected cases and deaths cases of COVID-19 worldwide at March 27th, 2020.

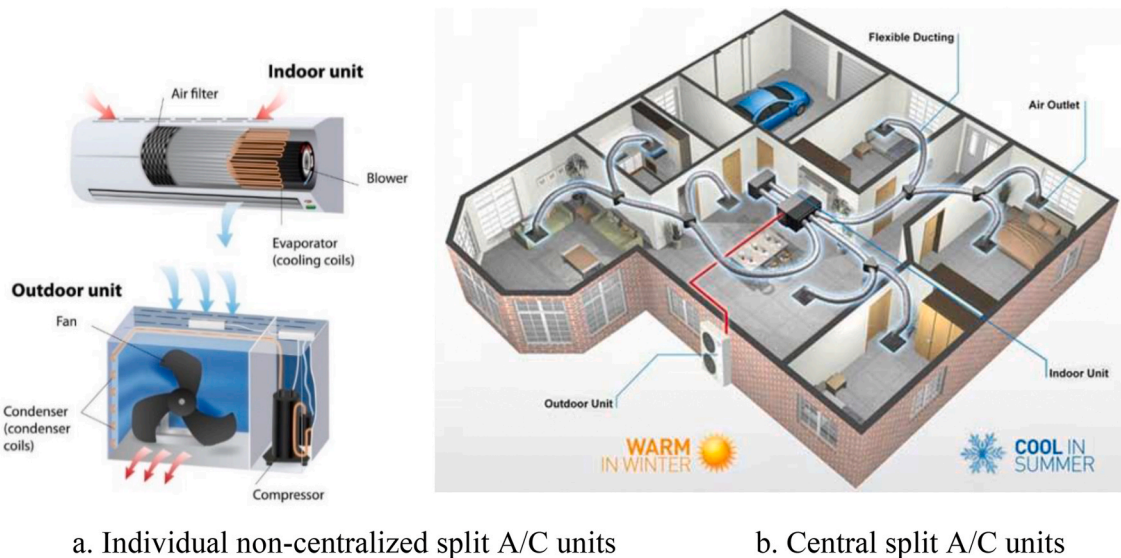
viability of COVID-19 (Lynch and Goring, 2020). The process of transporting outside air through air conditioning systems and their treatment with fine particles does not necessarily have 100% efficiency. Therefore, there is a possibility that some microscopic particles can escape in the treated air and carry the COVID-19 viruses that cause infection to the population. This requires reviewing the cycle and path of these devices and designing their components to ensure clean air without viruses. Air conditioning systems involve important components to be effective such as air handling units, filters, transporting ducts, and fans (Lynch and Goring, 2020). Reducing the transmission of infection through the air as a transport medium is an important goal to stop the spread of the epidemic through it, especially since all medical hospitals are centrally adapted and their air is forced to air-conditioned places. The risk of transmitting the epidemic infection through the air conditioning system of any type appears due to its treatment of air as a medium for heat transfer through the air conditioning cycle. Fig. 11 shows the heat transfer cycle through the air conditioner.

Air-conditioners of all kinds are among the most important basic necessities in practicing our daily life effectively and with quality to

achieve conditions of thermal comfort for humans, especially with high temperatures and humidity. The indoor air quality (IAQ) of air-conditioners leans on the quality and efficiency of air filters in addition to ventilation and exfiltration rate and is considered the first obstacle to achieve healthy conditions with air conditioning (Allam, 2020). In the next part, two complementary elements will be addressed in detail concerning the reduction of the rapid spread of infection to the reduction of respiratory diseases, especially the global epidemic of COVID-19, namely air-conditioner equipment and their accessories from ductwork, ventilation, and air purification technology.

5. Indoor air quality (IAQ)

Air quality and its purity play a significant function and a vital role in the current state of the corona pandemic, as it is a facilitator for the coronavirus infection in polluted places. Indoor air quality means the air purity in and around buildings and facilities is particularly in relation to the health and comfort of building residents. Insufficient ventilation can lead to a rise in the concentrations of pollutants carrying the coronavirus



a. Individual non-centralized split A/C units

b. Central split A/C units

Fig. 11. Heat transfer cycle through the air conditioner.

in closed places by not feeding enough outside air (fresh air) to further dilute these pollutants and not removing the indoor air pollutants outside the ventilated area (exhaust air). Temperature and humidity are among the factors affecting the reduction or increase of the spread of the coronavirus. In particular, air quality at the present time of the coronavirus pandemic is viewed with more interest in working to achieve high air quality through several means to mitigate and prevent the spread of the coronavirus. The achievement of air quality or indoor air quality can be studied through the illustrated planning. In this research, the IAQ will be studied by improving the ventilation process, air conditioning systems, and their components, to confront the emerging situation of the coronavirus to mitigate and prevent the novel pandemic. The current research studies air quality by addressing and improving ventilation and air conditioning systems from a separate view of the current state of the coronavirus epidemic. The following diagram in Fig. 12 explores how to address and improve indoor air quality in light of both ventilation and air conditioning systems.

5.1. Ventilation and coronavirus (COVID-19)

Ventilation is significant to work in fighting to resist the diffusion and transmission of infectious diseases through the air, as recognized by ASHRAE and the Federation of European Heating, and the Ventilation and Air Conditioning Associations (REHVA) partners (Friedlander,

2020; LiuaHang et al., 2019). However, with the SARS-CoV-2 pandemic, the ventilation system at home, office, or another facility must be revised in terms of this newcomer.

Ventilation is important, especially in applications that require significant air change. The air is filtered by the air conditioners and released in the specified area. When it comes to hospitals, we move to a deeper level with specific rooms that need either positive or negative pressure in relation to the surrounding areas. The intent concerning a positive pressure is to guarantee that airborne pathogens do not pollute the patient or the equipment and supplies in the space. Thus, extra air is supplied into these rooms to push pollutants away from entry (Refrigeration, 2016). The negative pressure, which absorbs air from the room, is used to withdraw any possible contaminants from the area and exhaust them to the outside air. Passive chamber pressure is an isolation technique utilized in hospitals to restrain cross-infection from one room to another, especially in the epidemic of COVID-19. From the above, it turns out that the pressure of the isolation rooms of those infected with the COVID-19 pandemic should be transferred from positive pressure to negative pressure with the use of suitable air filters at a purity level of 99.99% (Guidelines for the class, 2007) as displayed in Fig. 13.

5.1.1. Improving ventilation through air purity

Air cleaning could be performed to obtain indoor air quality using two methods: dry cleaning and wet cleaning. There are several ways to

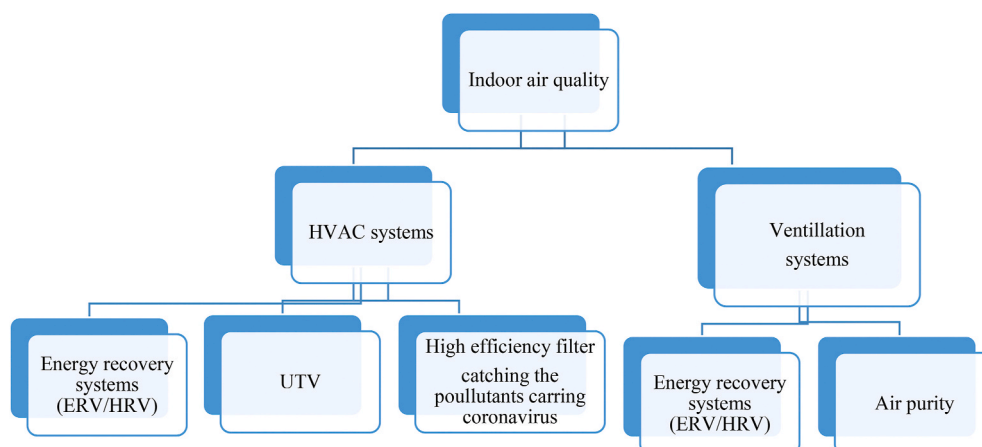


Fig. 12. Indoor air quality strategies in light of both ventilation and air conditioning systems.

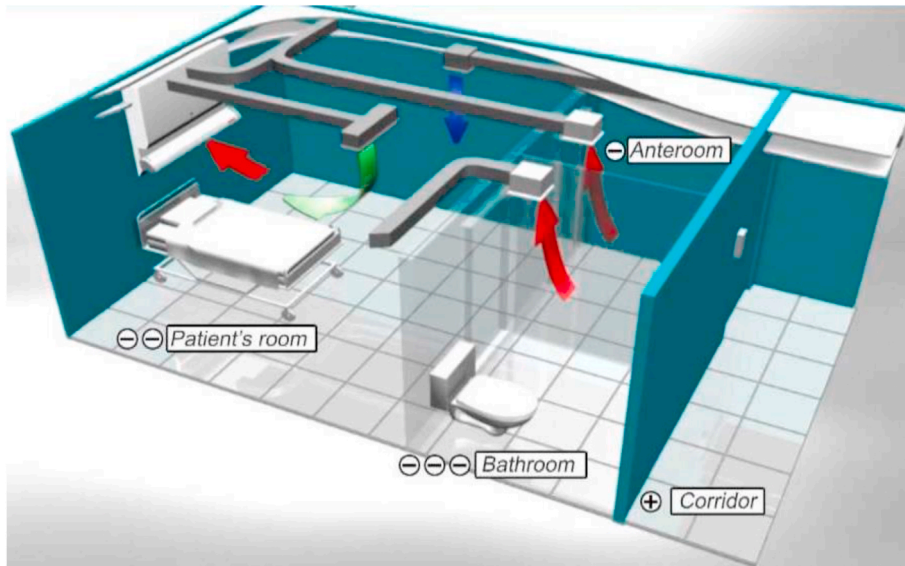


Fig. 13. Appropriate pressure distribution in the isolation room, the accompanying bathroom, and the corridor [according to (Friedlander, 2020) (LiuaHang et al., 2019) (Guidelines for the class, 2007)].

purify the air from harmful small particles that carry viruses and microbes and transmit the infection to humans. The following diagram in Fig. 14 manifests these methods.

Air purifiers are used for many different purposes. In homes, as an example to improve the cleanliness of the air, special types of air purifiers help eradicate pollen and dust, thereby relieving those suffering from fever and other allergies. Hospitals and special care departments use air purifiers to keep the surrounding air clean and reduce the transmission of infections that may be deposited in the ventilation system.

5.1.1.1. *Liquid air purification systems.* It is a washing system installed in the place where you want to purify its air and a washing machine, such as fresh air, return air, mixed air, and supply air. Such systems work on washing the air before it is heat-treated and distributed to the places to be fed. This system is like the system used in the cooling towers where the desired air is washed with a large amount of water dispersed from top to bottom or through a design that ensures the distribution of an abundant amount of water that washes air from all sides. Moreover, some chemicals and sterilizers can be added to sterilize the air used in air conditioning operations. In addition, other materials can be added to change the viscosity of the water so that it ensures polarization or attracts unwanted materials to the air to be treated. Fig. 15 shows the system of liquid air purification in which air is treated in the cooling tower provided with chemicals and sterilizing materials and then the treated air flowed in the HVAC system to be cooled. After that, the cold treated air is pushed to the feeding, mixing, or return points.

5.1.1.2. *Dry air purification systems.* As shown in the block diagram of Fig. 14, the dry air purification systems use UV technology and air filter to improve the air quality.

A. Using ultraviolet lighting to purify and sterilize the air

Ultraviolet radiation from special lamps is used to sterilize surgical instruments, where ultraviolet radiation kills bacteria and viruses. The use of ultraviolet rays in the cooling files work to destroy the DNA and burn the external wall of viruses and microbes and eliminate them completely from the cooling files and keep them clean from molds and pollutants. It also eliminates the spreading of diseases and causes of infection. Thus, it reduces the cost of cleaning the coils and drainage basins and restores the process of transferring the heat to nearly the original level. Researchers' experiences at Florida Hospital in America showed the ability of UV radiation to fight infection, save maintenance, improve performance, and reduce costs. As a result of experiments and measurements carried out by the Energy Association of Texas, USA, over a year for an air conditioning unit that uses ultraviolet light, a 28% decrease in energy consumption is observed for this unit in comparison to other similar ones. Fig. 16 presents the installation of ultraviolet light bulbs in split air-conditioning units, cooling coils, inside the duct, and filter, and Fig. 17 manifests the difference of air conditioning components before and after using UV.

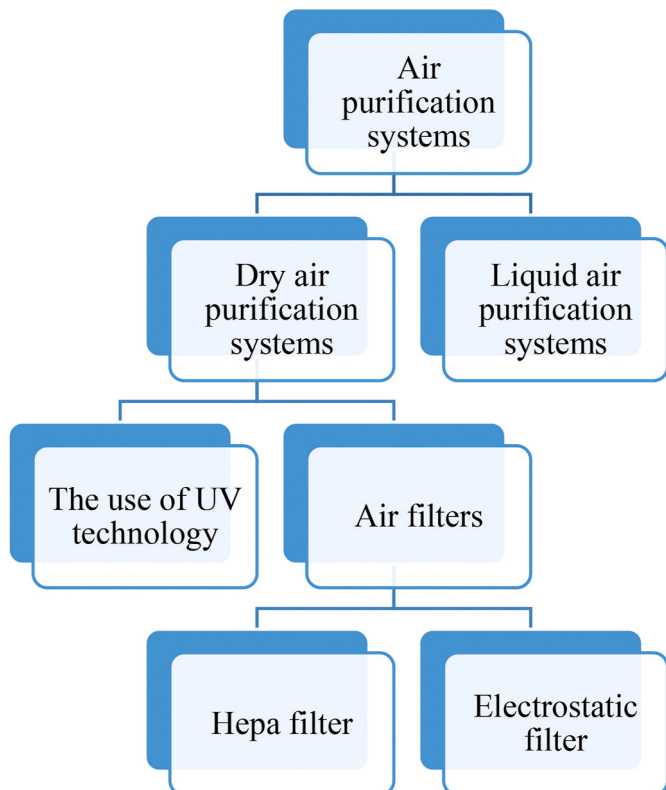


Fig. 14. Block diagram of air purification systems.

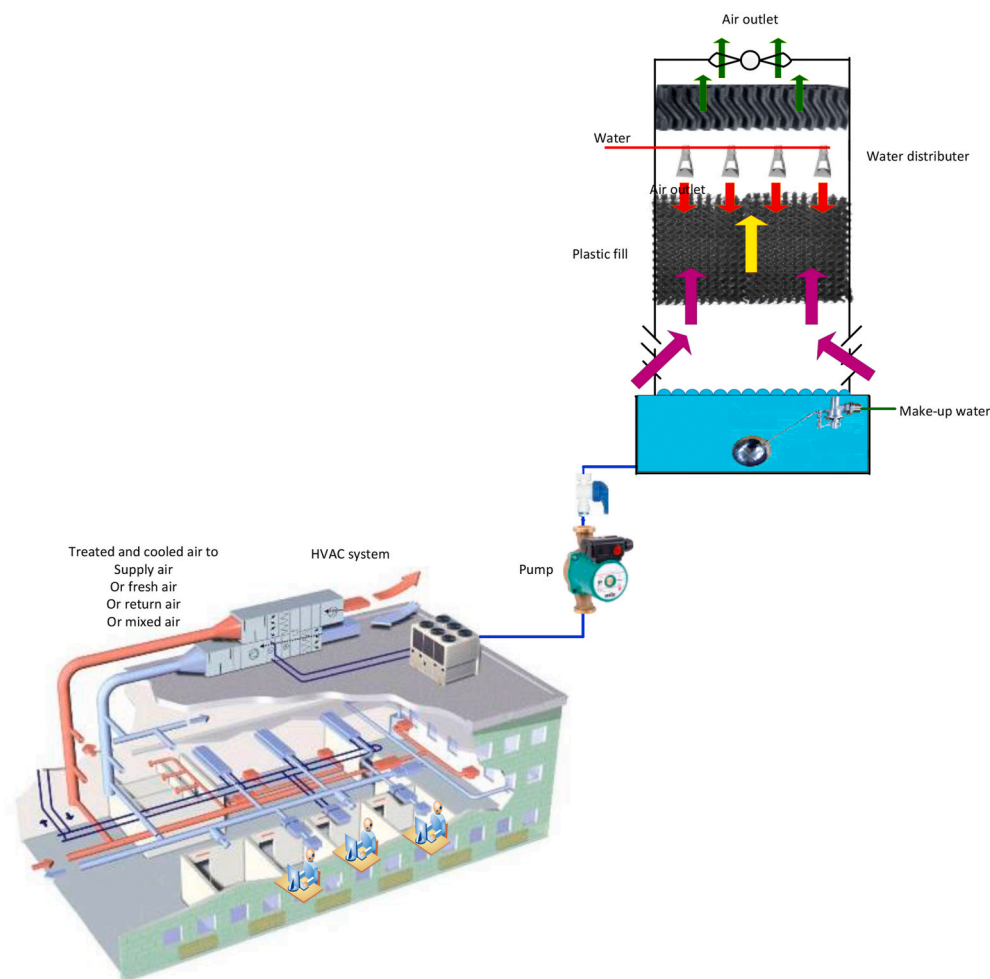


Fig. 15. A schematic diagram of liquid air purification systems.

B. Dry air purification systems with air filter

To get clean air through the building and reduce the coronavirus spread, Camfil (www.camfil.com/en/insight) offers a model called city M air purifier that contains a 99.95% HEPA filter and a molecular filter to control other gaseous pollutants. Fig. 18 illustrates the situation before and after the installation of the model suggested by Camfil city M air purifier.

Air filters play an important role in air quality as a wall block for fine particles that are loaded with viruses and others. The selection of filter basically depends on the purpose for which it is used. Impurities may be classified according to its size as follows: Pollens = 9–80 μm , Mould spores = 3–50 μm , Fine ash = 0.7–60 μm , Bacteria = 1–10 μm , Tobacco smoke = 0.1–7 μm , Viruses = up to 0.1 μm (Kumar Satheesan, 2020a). Filter media is available to eliminate any volume, but very fine particles require a deep, bulky and costly filter, which in itself forms a high resistance to airflow and, therefore, requires high fan energy. The filter used in the event of spreading pandemic must have the ability to prevent the particles loaded with coronavirus (COVID-19). In order to solve the problem of finding a high-specification filter capable of blocking small particles loaded with viruses, it is necessary to design filters less than 0.01 μm preceded by another filter to reserve relatively larger particles with specific mounting frames so that contaminated air cannot escape the edges. The alternative type of filter for holding very fine particles is high-voltage electrostatic precipitation on the plates or wires inside the filter bank to transfer a constant charge to the dirt particles. Impurities are usually cleaned with plates by removing the stack and washing. Fig. 19 depicts the filtering strategy of air cleaners through conditioned

spaces.

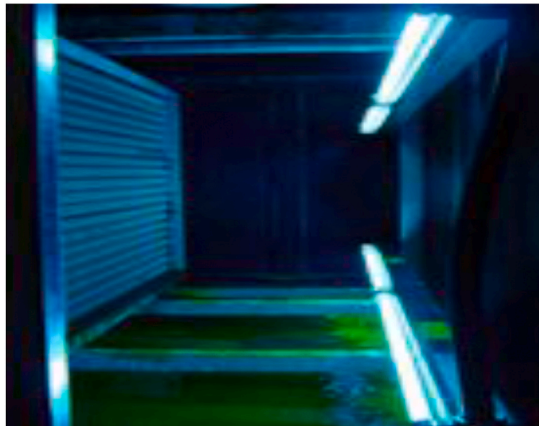
For treating and improving the efficiency of electret filters, it is needed to prevent particulate matter in indoor environments which are excessively utilized in HVAC equipment. Tobias et al. (2020) conducted a study to treat the filters with a technique of saturated isopropyl alcohol (IPA) vapor (Chang and Lu, 2003). Some researchers improved the efficiency of filters through added reactive materials that can capture most bacteria and viruses. Oluwatoyin Sunday and Sakugaw (2020) confirmed that the generation of O_2 produced by irradiating a sensitizer-impregnated filter is efficient and that it can be incorporated into the saturated filters. Filters like these could find a potential application to inactivate bacteria/viruses in the indoor environment by associating them with air purifiers.

Electrostatic precipitator filter is manufactured to reduce nanoparticles and micron-size in indoor air environments during a process in negative air ionizer with the help of a parallel plate collector. Moreover, the ionization process includes four (ION4) or eight (ION8) corona needles generated by a negative DC high voltage (4–7 kV) as seen in Fig. 20. Fractional efficiency (expressed in number) is examined using very fine nanoparticles and aerosols according to various engineering, environmental, and many operating conditions including concentration, relative humidity, collector and ionizer voltage, collector length, number of needles, and airflow rates.

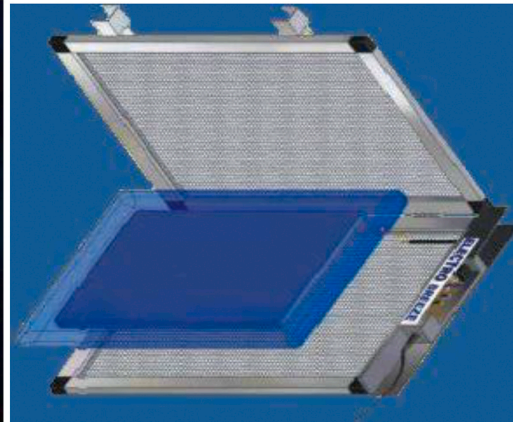
Under optimal conditions of operation, the findings reveal that the efficiency of the particles with a diameter of 10–25 nm was 94%, and with 30–300 nm, efficiency was 99% (Chen et al., 2020). This study presented the ION8 ionizer performance to remove particles from the interior environment of places because it provides high efficiency and



(a) Ultraviolet light bulbs in split air-conditioning units



(b) Ultraviolet light bulbs in cooling coil



(c) Ultraviolet light bulbs in cooling coil



(d) Ultraviolet light bulbs in air duct



(e) Ultraviolet light bulbs in cooling coil

Fig. 16. Installation of ultraviolet light bulbs in split unit the installation of ultraviolet light bulbs in split unit air-conditioning units, cooling coils, inside duct, and filter.

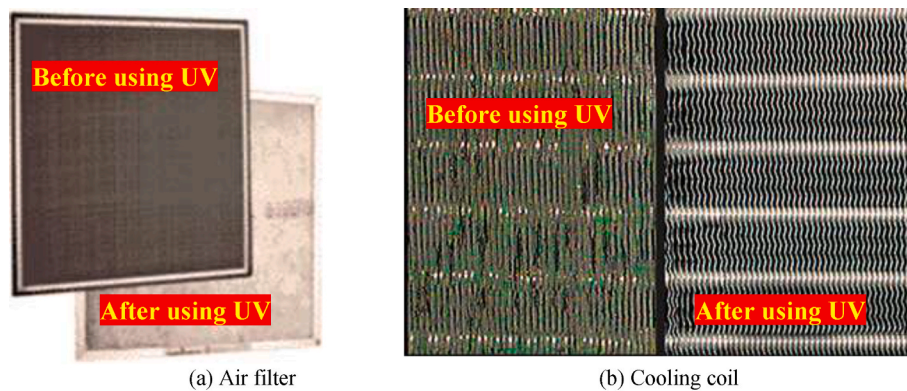
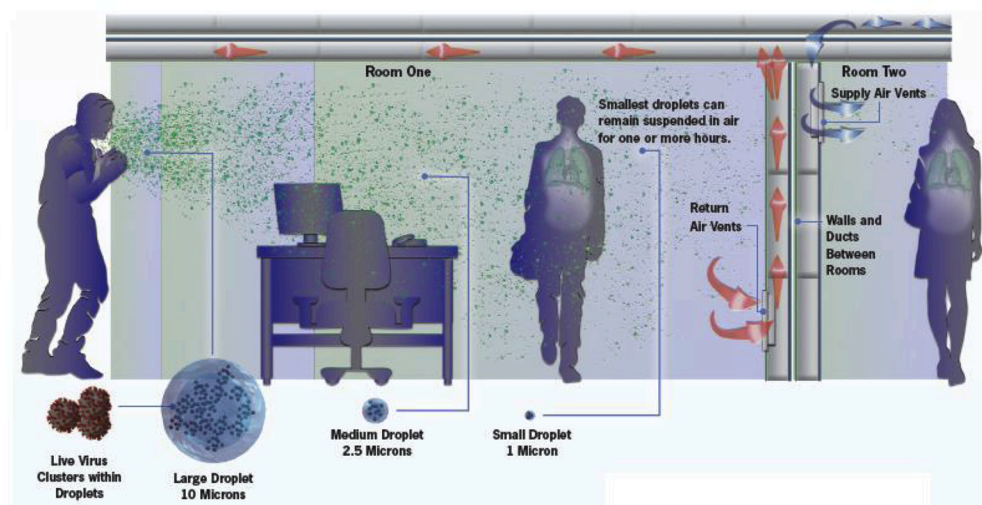
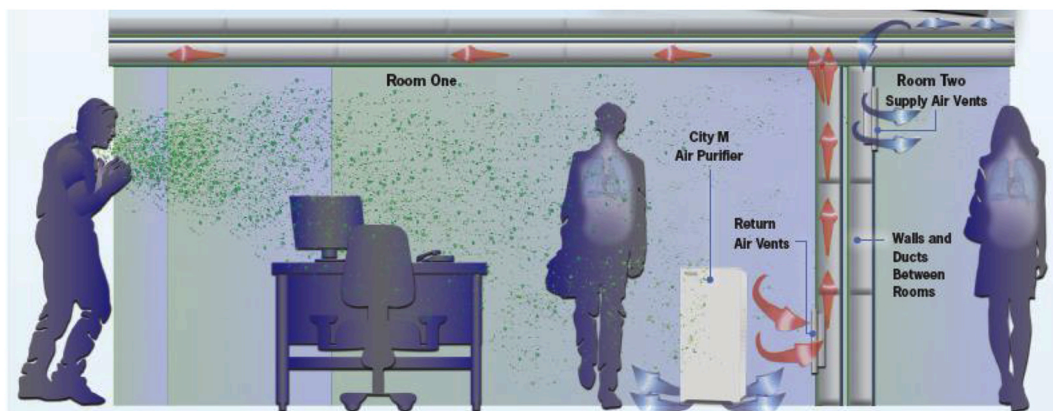


Fig. 17. Factors affecting IAQ of air conditioning components before and after using ultraviolet light bulbs.



(A) Position before installed city M air purified.
(Simple sneeze, pathways of respiratory droplets)



(B) Position after installed city m air purified.

Fig. 18. The situation before and after installed the model city m air purifier (www.camfil.com/en/insight).

low ozone production (<5 ppbv) with a small pressure drop and higher energy saving. However, removing nanoparticles less than a few tens of nanometers presents a technological def. Practical synergy was investigated to remove multiple classification pollutants in the indoor air in a 3 m³ environmental chamber using an integrated technique of electrostatic precipitation and catalytic decomposition of multiple sources of

complex pollutants carrying infectious microbes in the indoor air. Simultaneous and effective removal of particulate matter, VOCs and ozone were achieved. The effective combination of technologies has improved the quality of indoor air synergistically. With electrostatic deposition of particles (94%–100% removed), the UV catalysts and VOCs (100% removal) are oxidized within 20 min (Zeng et al., 2020).

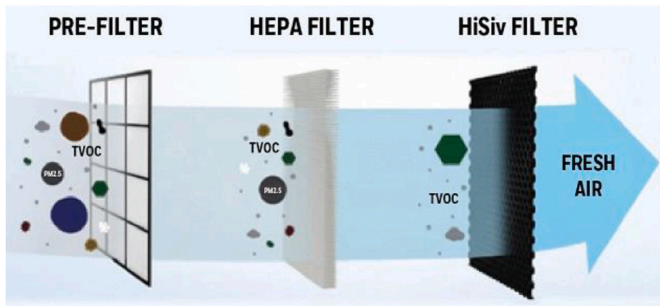


Fig. 19. Filtration stages of electronic air cleaners.

Fig. 21 explores the purification of air through the ionizers of four (ION4) or eight (ION8) corona needles.

Xu et al. (2010) investigated the cases of 30 children with asthma for six weeks, who were separated and observed in two groups into two separate rooms. The first room with 15 children and air cleaning/ventilation unit (HEPAiRx), whereas the second room with 15 children and a ventilation unit but without air cleaning system. An AirAdvice indoor air quality multi-meter is utilized to observe the IAQ parameters such as temperature, relative humidity, particulate matter (PM 0.5–10 mm), carbon monoxide, carbon dioxide, and total volatile organic compound (TVOC) concentrations for each bedroom. Both condensed exhalations (EBC) and peak expiratory flow (PEF) were collected as measures of pneumonia. The findings revealed that the concentrations of TVOC and PM decreased with HEPAiRx running by approximately 59% and 72%, respectively. Air cleaning with ventilation could effectively reduce symptoms of asthma patients. MacIntosh et al. (2008) presented an experimental model to measure the efficacy of WHF for the removal of particles. Along the lines of standard CADR, whole home clean air delivery rate (WHCADR) is estimated based on reports airborne particulate removal rates for air cleaning systems. Central

ventilation was used in the test building similar to the building of the National Institute of Standards and Technology (125.5 square meters with a height of 2.5 m and contains seven rooms and a bathroom), taking into account the effect of dust on the building’s surfaces as seen in Fig. 22.

The authors compared the effectiveness of different types of central filtration systems for air conditioning, refrigeration, and room air cleaners. Standard fine dust was sprayed inside the building, different air cleaning units were run for 80 min and each unit tested 6 times with the HVAC system running without the filter to estimate particulate reduction by sedimentation in ductwork then calculate WHCADR for each test in cubic meters per minute. The results included the following:

1. Operating the central ventilation system without a filter, where approximately a third of the 3–5 μm aerosols and one-half of the 5–10 μm aerosols were removed, but less than 10% of the smaller particles.
2. Operating the central system with a 1-in MERV 2 filter or portable ion air cleaner (operating in three rooms simultaneously) did not produce better results than not having a filter.
3. Operating the three ionic air cleaners resulted in an increase in micrometer particles during the tests. The finding is due to the reaction of VOCs and ozone produced by ionizers.
4. Running one HEPA PRAC in one room did not provide air cleaning in other rooms in the building.
5. Purifying the air can be achieved as long as the WHCAD R is utmost than the whole home air exchange rate (the average US resident air exchange rate is 0.71 air change per hour (Yamamoto et al., 2010). The studied three air filters achieve high-efficiency of HVAC as did the operation of HEPA PRAC in five rooms simultaneously. Five HEPA units are installed in separate rooms in a building containing a WHCADR of only 58% of the theoretical CADR for individual units because the room units are unable to draw air from other places outside the room. Feng and Cao (2019) developed the flat enhanced



Fig. 20. Ionizers of four (ION4) or eight (ION8) corona needles (Oluwatoyin Sunday and Sakugaw, 2020).

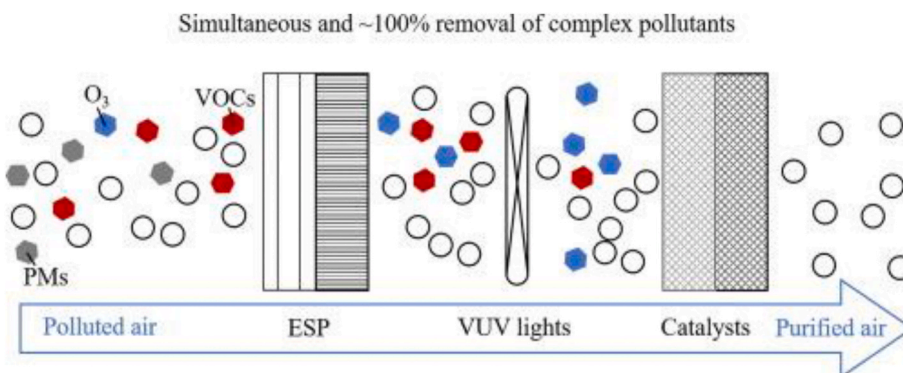


Fig. 21. Purification of air through ionizers of four (ION4) or eight (ION8) corona needles (Zeng et al., 2020).

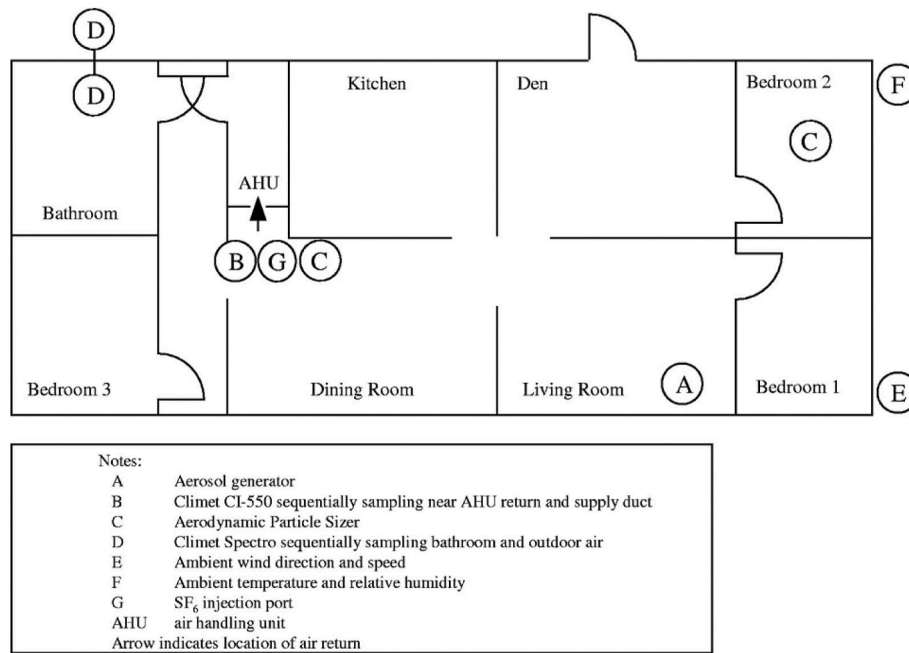


Fig. 22. Locations of aerosol generator and instruments of the test building (MacIntosh et al., 2008).

electrostatic air filters (EEAF) to be used as an enhanced pleated air filter (EPPF) for fine particles (0.01–10 μm) to reduce energy use as would happen with high-efficiency pair filters (HEPA) provided that the design meets ASHRAE standards as seen in Fig. 23. The results depicted that the EEPF filter gives a filtration efficiency of >98% and saved 70% energy consumption compared to a HEPA filter.

The results explored that the EEPF filter meets a filtration efficiency of >98% and saved 70% energy consumption compared to a HEPA air filter. Sun et al., 2020 studied the survival rates of bacteria and fungi of *E. coli* and *B. subtilis* for positively charged electro-filtration media and modified chitosan that was used in ventilation systems on an aircraft that may enter into the indoor air and pose a threat to passenger’s health. Fig. 24 presents the simulation test rig of the bacterial survival rate on the blankets.

The results explored that after 6 h, the survival rate of *E. coli* bacteria on the positively charged electret filtration medium is reduced to less than 30% compared to the uncharged filtration media. Furthermore, after 120 min, the survival rate of *E. coli* on pure nylon, chitosan dipped nylon-6, and nanofibrous filter media is diminished to 8.4%, 7.1%, and 2.8%, respectively. Park et al. (2020) provided a new methodology for determining the antiviral performance of the air filters against airborne infectious viruses such as COVID-19 and others. Antiviral air safety tests were performed using the air-media test, in which an air hardener was placed against a non-infectious haze virus. Moreover, the liquid media test method is the second stage, in which the fittest one is introduced

into a liquid medium containing a non-infectious virus as displayed in Fig. 25.

A correlation was inferred by comparing the obtained sensitivity constants between the two averaged tests and a correlation of the medium air test found with the infectious virus. After confirming that the relationship does not depend on the virus species, the correlation was used to derive the air and medium test results from the liquid media test results. By depositing, Balagna et al. (2020) developed a nano-coating consisting of nano-silver/silica compound on the surface of a non-woven, fire-based glass filter that has the ability to confront diseases and viruses without altering the filtration performance of the filter as seen in Fig. 26.

The results showed that the improved air filter completely inhibits the growth of microorganisms even when exposed to bio-aerosols with high bacterial concentration. The filter works as an anti-bacterial for long periods of up to one month. The innovative nanocomposite coating imparts long-lasting anti-microbial properties to improve the performance of filtration systems to protect against bacterial contamination and reduce the risk of infectious viral and bacterial diseases with minimal maintenance effort. Nirmala et al. (2021) removed viral particles in air filters to reduce PRRSv infection by milling filter samples with liquid nitrogen, along with TRIZol RNA extraction reagent for both PRRSv and IAV virus. PRRSv was detected in 27% (12/44) and IAV was detected in 66% (29/44) of the filters. The presence of PRRSv and IAV in the filters used shows evidence of the inter-flock aerosol diffusion of these viruses. Min et al. (2018) produced air filters with a new technology consisting of

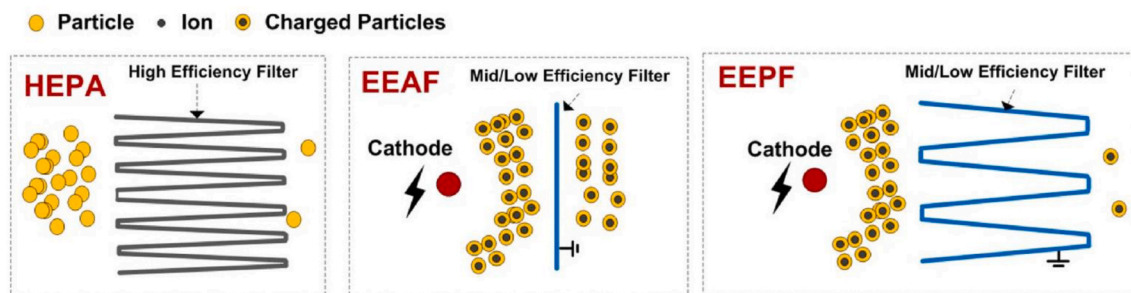


Fig. 23. Technique details of HEPA, EEPF and EEAF filter (Feng and Cao, 2019).

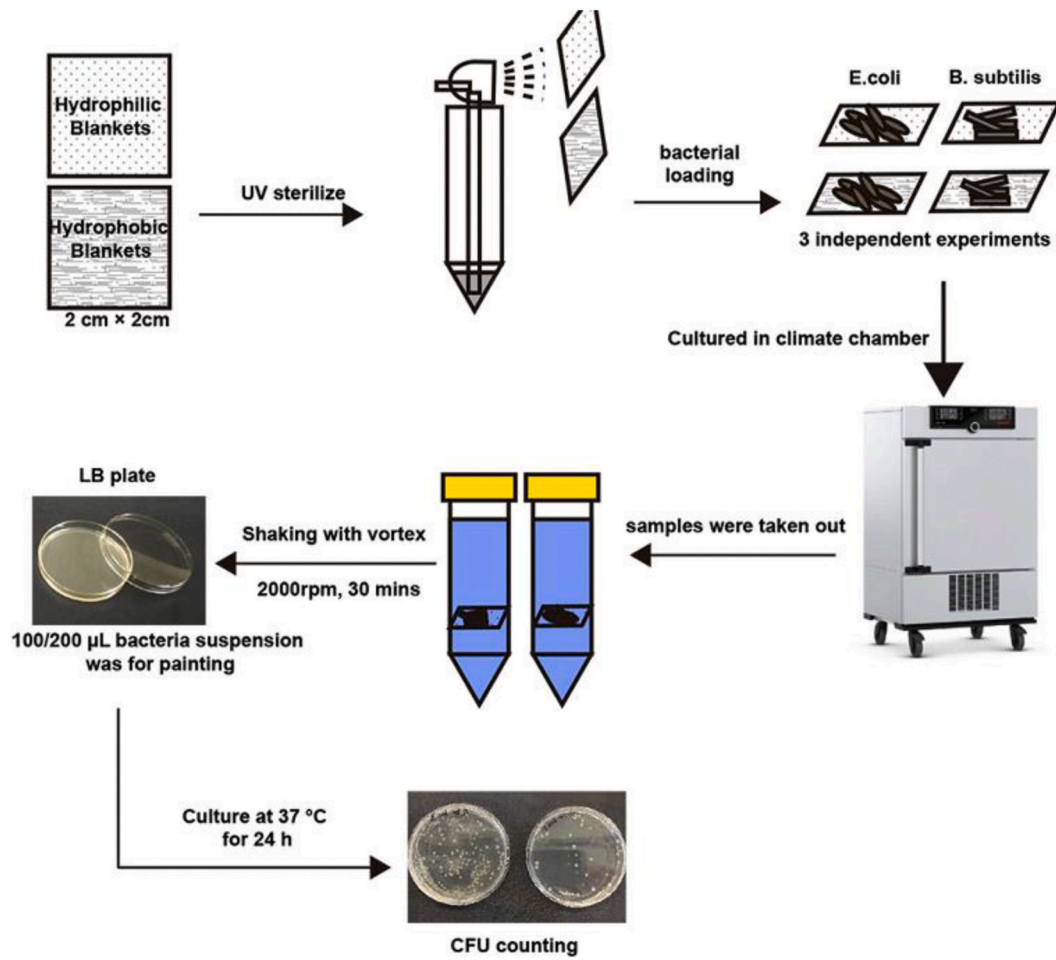


Fig. 24. Test rig of the bacterial survival rate on the blankets (SunYang et al., 2020).

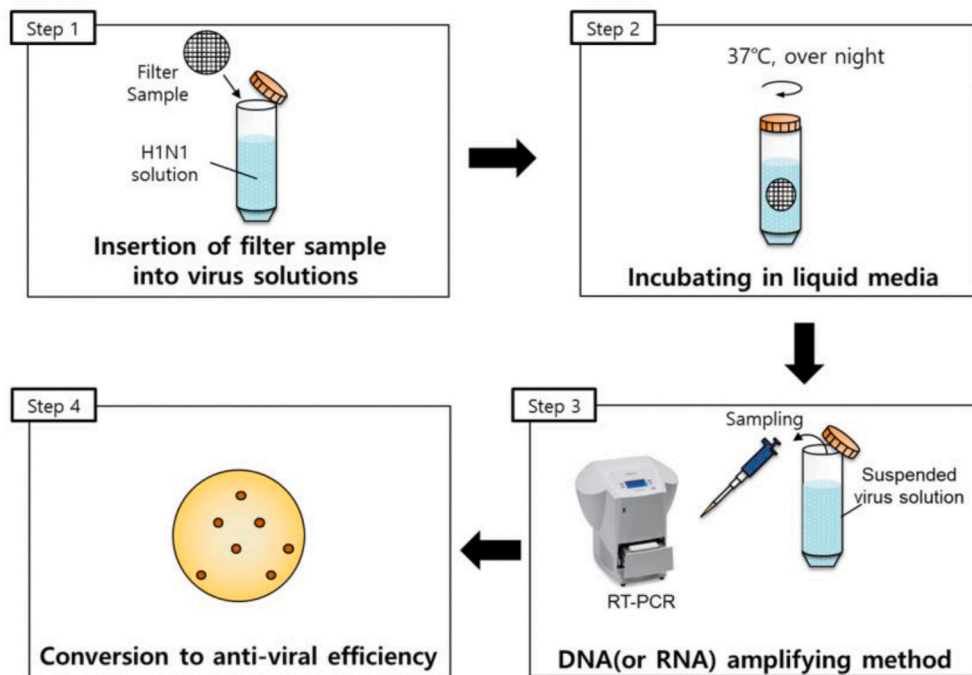
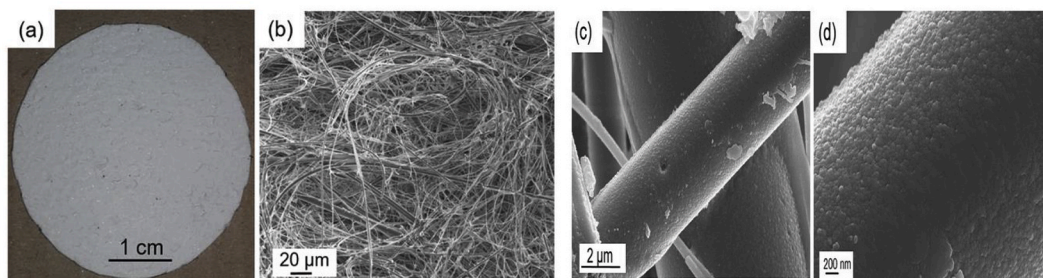


Fig. 25. Procedures for estimating anti-viral capability contra the H1N1 virus (Park et al., 2020).



(a) Photograph of Glass fire-based filter, (b) SEM of the uncoated glass fire random structure and, and (c,d) SEM of the coated filters by nanocomposite of Ag/SiO₂.

Fig. 26. SEM of uncoated and coated glass fire-based filter (Balagna et al., 2020).

silk protein nanofibers on a transparent glass window by electrostatic spinning to filter the air from particulate matter (PMs) and volatile organic compounds that may harm public health. Fig. 27 illustrates a high-efficiency silk nanofibrous air filter (SNAF).

The optical properties of SNAFs are transparent and dispersive for viewing and controlling space temperature with a filtration efficiency of up to 90% and 97% for particles of sizes less than 2.5 and 10 μm. The

performance of the SNAFs exceeds the efficiency of the HEPA filters, and the SNAFs saturated with organic dyes exhibit hazardous, volatile, and environmentally friendly smoke sensing properties. Xia and Chen, 2020 carried out a group of experiments on a nanofiber air filter by exposing it to PM_{2.5} in indoor environments to understand the evolution of liquid aerosol wetting on PM_{2.5} removal efficiency and pressure drop while exposing the incense particles to the nanofiber filter medium and

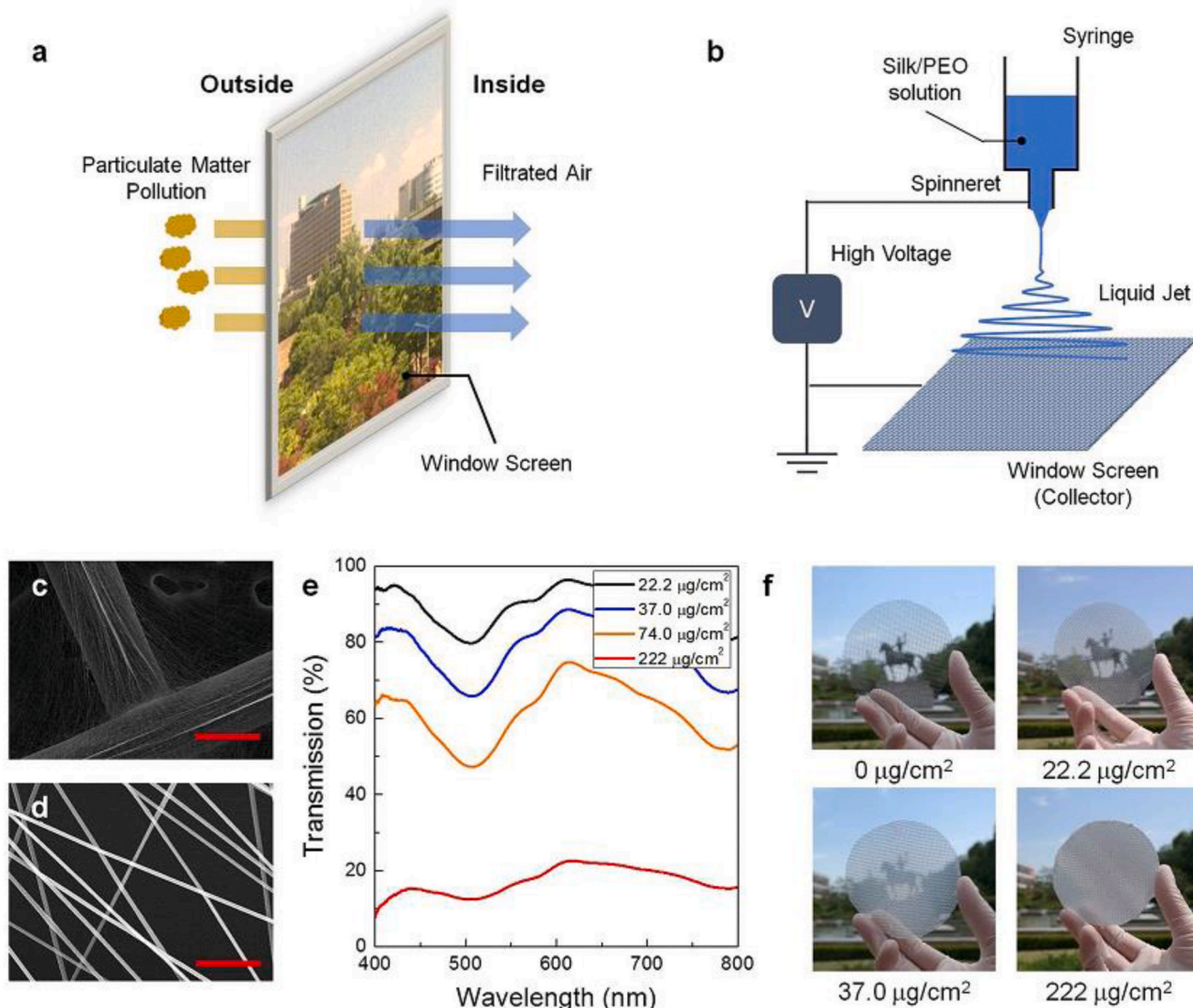


Fig. 27. A high-efficiency silk nanofibrous air filter (SNAF) (Min et al., 2018).

observing the nanoscale interactions between the incense molecules and the nanofiber network using SEM micro-photograph. Fig. 28 shows the diagram of the electrospinning procedure (a) and a photographic view of a nanofiber air filter media (b).

The results showed that with increasing mass loading, $PM_{2.5}$ removal efficiency decreased due to pore enlargement of the filter medium. Bian et al. (2020) investigated the effect of electrospun nanofiber nylon filters to remove harmful $PM_{2.5}$ particles from the air for various parameters such as filter thickness, packing density, and fiber diameter. 25 nanofiber air filters were tested and the $PM_{2.5}$ removal efficiency was measured for each sample with different face speeds. Fig. 29a presents the common HEBA filter for holding a particle with high resistance whilst Fig. 29b depicts the nanofiber air filter for holding a particle with low resistance.

The results manifested that the $PM_{2.5}$ removal efficiency of nylon fiber filters is in a negative response with the fiber diameter and a positive relation with the filter thickness and there is no relationship with the packing density. Leung and Sun (2020a) aimed at developing conventional air filters (such as ventilators, face masks, filter/medical respiration systems) using electrically charged multi-layer/multi-unit nanofibers with exposure to 90% of an aerosol of COVID-19 at a volume of 100 nm. The airborne nanoscale aerosols with amorphous COVID-19, the droplets of the monodispersed size of NaCl, and test oil (DOP) together are reacted simultaneously and are of different sizes to complicate the filtration process. The filters were arranged in 2, 4, and 6 multi-stacking units each with 0.765 g/m^2 of charged PVDF nanofibers (average diameter $525 \pm 191 \text{ nm}$) as displayed in Fig. 30. The results manifested that the electrostatic effect increases the mechanical efficiency by 100–180% depending on the number of stacking units in the filter. The charged nanofiber filter achieves 88%, 88%, and 96% filtration efficiency for ambient aerosols respectively for virus sizes of 55 nm, 100 nm, and 300 nm as manifested in Fig. 31a.

The filter's filtration efficiency reached 92%, 94%, and 98% (qualifying for 'N98 standard') using a single dispersible NaCl spray of 50, 100, and 300 nm, respectively as depicted in Fig. 31b. The PVDF nanofiber filter provides good protection against the airborne COVID-19 virus and nanoscale aerosols from contamination and is at least ten times more breathable than a medical N95 mask.

Leung and Sun (2020b) developed air filtration technology for the purpose of capturing the airborne and rapid spread COVID-19 virus through the respiratory system, with the size of the aerosol set to 100 nm (nanoscale aerosols) not 300 nm as is done in most research with the use of 4 filters made from PVDF nanofibers of medium diameters 84, 191, 349, and 525 nm electrostatically charged via corona discharge technique. Fig. 32 explores the air filtration technology used in the investigation.

The improved filters achieved protection to prevent the spread of the

COVID-19 virus and reduced air pollution that lead to deadly chronic diseases. The suggested filter can capture the rapidly spreading airborne COVID-19 virus, with an aerosol size up to 100 nm (nano-aerosols).

5.1.2. Ventilation with energy recovery systems (ERV/HRV)

To meet the internationally defined standard of ventilation rates of ASHRAE 62 without increasing HVAC capacity to save capital and operating costs, energy recovery ventilation systems are supplied with Eco Fresh Energy Recovery Wheels (ERW). The ERW technology is used to recover 75% of both sensible and latent energy from stale exhaust air and transfer it to fresh air (outdoor air). The rotating wheel transfers both sensible and latent energy between the counter flowing exhaust and the air supply to get more fresh air at lower energy costs within the conditioned area (cooling/heating/dehumidification/humidification) (YangLi et al., 2015). Research implied that ERV can be energy efficient and minimize indoor air pollution for modern buildings, and enhance indoor working and living environment (Zhang and Zhang, 2016; Ben Ghida, 2019). To ensure IAQ through improving the ventilation process in the case of the novel coronavirus, the ventilation could be provided with Heat Recovery Ventilation (HRV) or Energy Recovery Ventilation (ERV). These devices enable us to adjust and control the condition of supplying indoor air directly for the case of ventilation or as one component of the air conditioning system for energy recovery, and hence it ensures IAQ. The heat from the return air is transferred to the supply air at the heat recovery core in the ERV in the winter season. The cycle is reversed in the summer season, as heat is transferred from the outside air into the exhaust air, causing cooling for the supply air as shown in Fig. 33 (www.nyc.gov/RetrofitAccel).

In an ERV system, the ductwork is separated by an energy recovery core, which transfers the energy of heat and humidity. In winter, warm indoor air passes through the core of the ERV as it is exhausted, heating the fresh outdoor air and redirecting 50% of the indoor humidity to the place. In summer, the cycle reverses and the cool indoor air cools the outside hot air to restore energy. Moreover, ERV redirects 50% of outdoor humidity to outside; hence, ERV is a better choice in all climatic conditions except northern regions to provide thermal comfort all year round. Fig. 34 shows two modes of the ERV system. The first mode is the case of the outside air of low humidity where it is exchanged with the return air of high humidity causing supply air to the room of high humidity (Fig. 34a). The second case is the supply air with low humidity causing supply air entering the room with low humidity (Fig. 34b).

In an HRV system, the two air streams are separated by a heat recovery core, which will only circulate the heat energy. In winter, warm indoor air passes through the core of HRV as it is exhausted and heated to the incoming fresh outdoor air. In summer, the cycle reverses and the cool indoor air cools the outside hot air to restore energy. The HRV controls excess humidity in cold seasons by bringing outside air into the

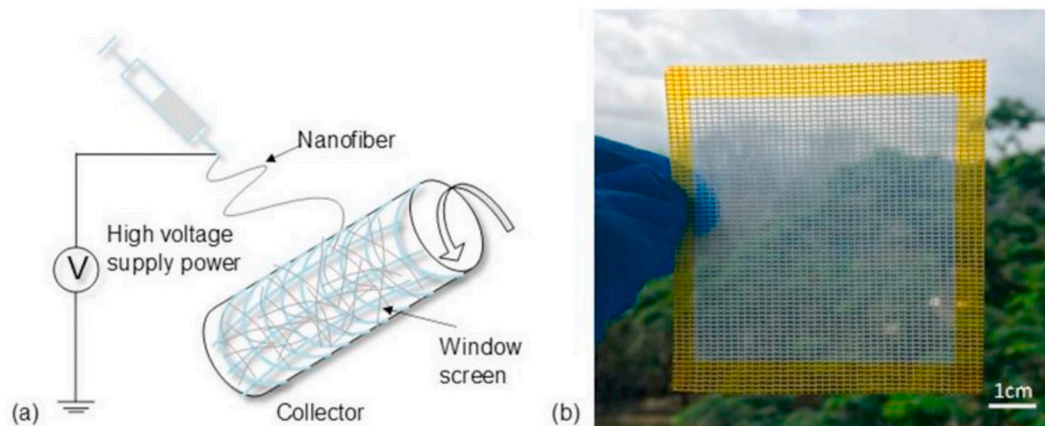


Fig. 28. (a) Diagram of the electrospinning procedure, (b) Photographic of a nanofiber air filter media (Xia and Chen, 2020).

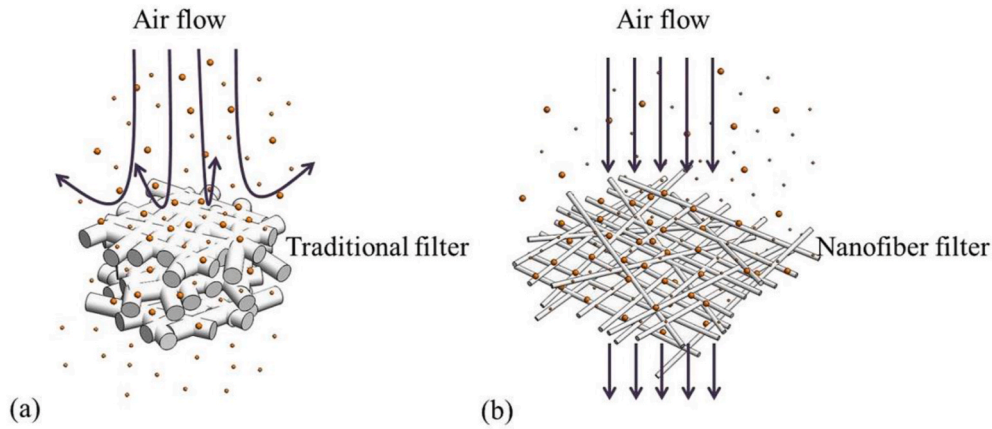


Fig. 29. (a) Traditional HEPA filter and (b) a nanofiber air filter (Bian et al., 2020).

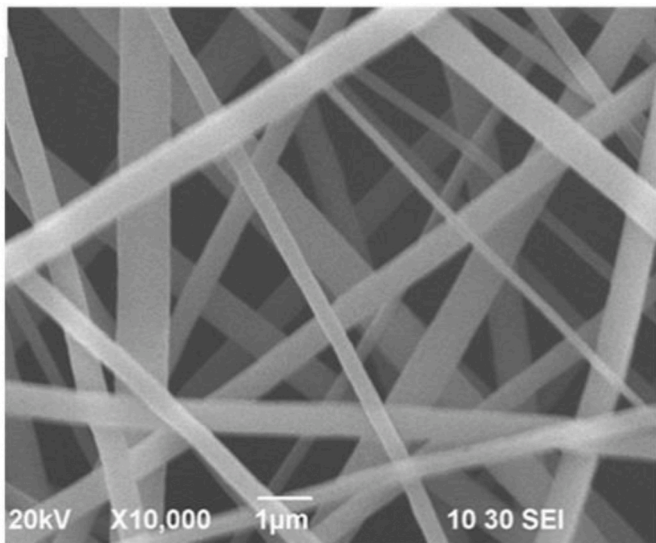


Fig. 30. PVDF nanofibers (Leung and Sun, 2020a).

house. Fig. 35 shows a schematic diagram of an HRV unit.

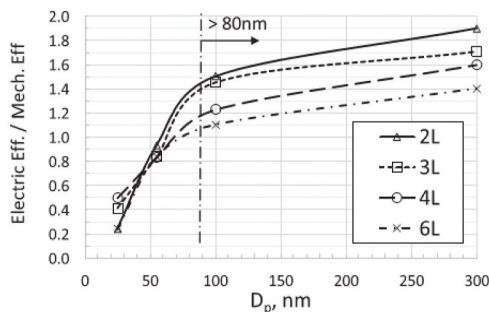
Most research studies confirm that in an energy recovery system if considering good airtightness and building insulation are taken into account, up to 90% of the ventilation heat loss can be recovered (Qi et al., 2019). It is possible to combine recovery ventilation systems with an HVAC system so that the same air ducts are used with the central heating or air conditioning system which is called the Integrated recovery ventilation and air conditioning systems, or it is possible to

design the ventilation system as a stand-alone system, as shown in Fig. 36, regardless of the cost. In the integrated system, the operation of both systems of recovery ventilation and central air conditioning is run in tandem. The direct-ducted system needs a separate network ducting of supply and return air ducts and is ordinarily utilized for radiant-heated homes without an HVAC system. Fig. 36 illustrates the ventilation units to recover the energy of HRVs and ERVs with the ducting system, while Fig. 37 manifests the air ducts for supplying fresh air to living rooms and bedrooms, for example. On the other hand, the exhaust air is drawn through ducts which are installed in the bathrooms and kitchens. Moreover, the figure shows that the ventilation ducts are separate from the heating and cooling air duct system.

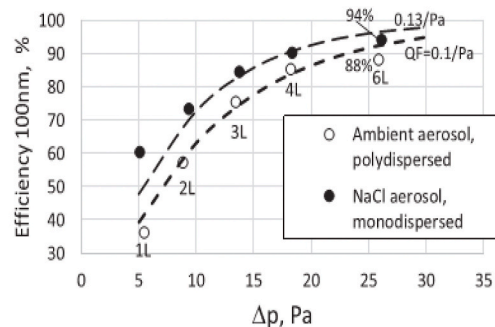
5.2. HVAC and coronavirus (COVID-19)

Air conditioning relies on dealing with the air as a heat transfer medium from an undesirable location to a conditioned space without objection (Peter et al., 2020). The unconditioned spaces cause thermal stress for residents, which affect their activity and health and reduce the resistance to the coronavirus infection in general especially at present. Hence, it is not advisable to disable HVAC systems to limit virus transmission. In this case, the filtration and ventilation accomplished by HVAC systems can minimize the airborne COVID-19 concentration and thus the risk of transmission through the air. Air supply systems can reduce virus transmission through built-in filtration with HVAC systems (Air conditioning and, 2020).

HVAC systems represent a vital requirement for human comfort in summer and winter with controlling temperature, humidity, air velocity at satisfactory values, and the control of the air supply from solid particles and dust to obtain a high quality of fresh air (IAQ). With the emergence of the new Corona pandemic (COVID-19) and its spread



(a) Electrostatic to mechanical efficiency versus particle diameter



(b) Efficiency versus pressure drop at 5.3 cm/s.

Fig. 31. Efficiency results of air filter of different parameters (Leung and Sun, 2020a).

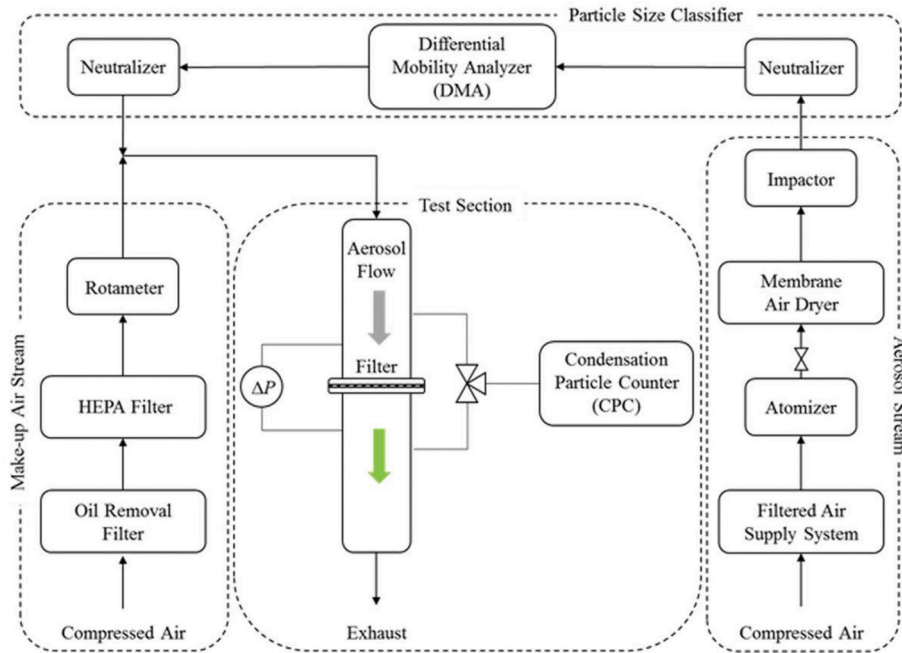


Fig. 32. Filter and aerosol generator test rig (Leung and Sun, 2020b).



Fig. 33. Energy Recovery Ventilator system (ERV) (www.nyc.gov/RetrofitAccel).

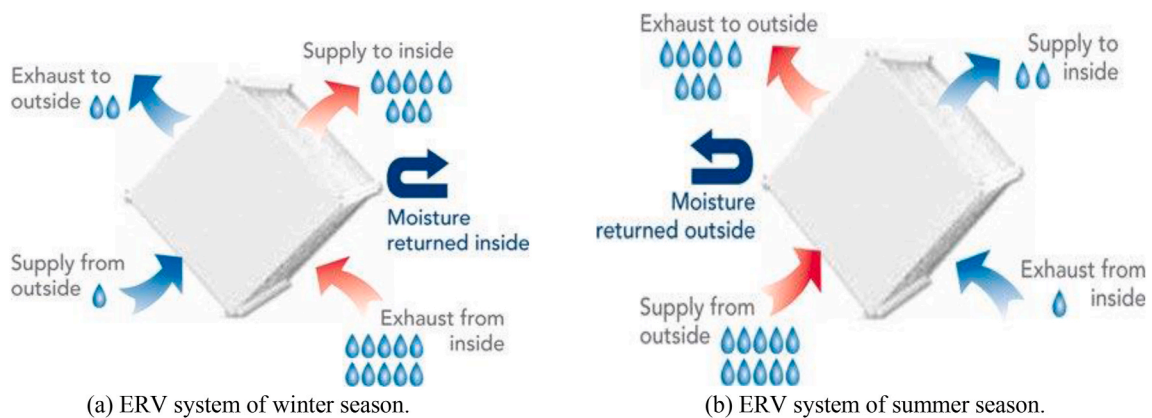


Fig. 34. Two modes of energy recovery ventilation systems (www.nyc.gov/RetrofitAccel).

worldwide with large number of infections and deaths due to this pandemic, air conditioning has become an important and vital factor in reducing and preventing the spread of this epidemic. Because of this new

situation of the coronavirus spread, it is required to review the HVAC systems and study their suitability for the new case of the pandemic. Hence, it is required to review the construction and design to examine if

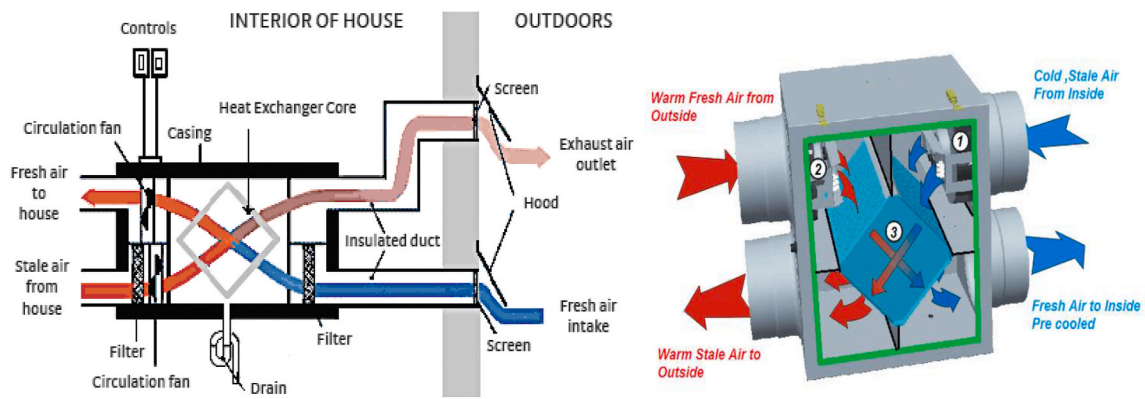


Fig. 35. Schematic diagram of an HRV unit (<http://www.prostar-mechan>).

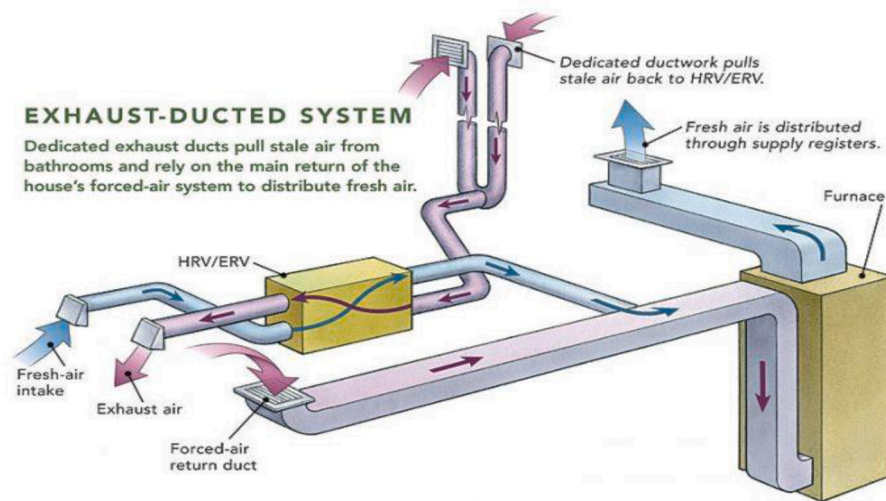


Fig. 36. ERV unit with air ducting system.

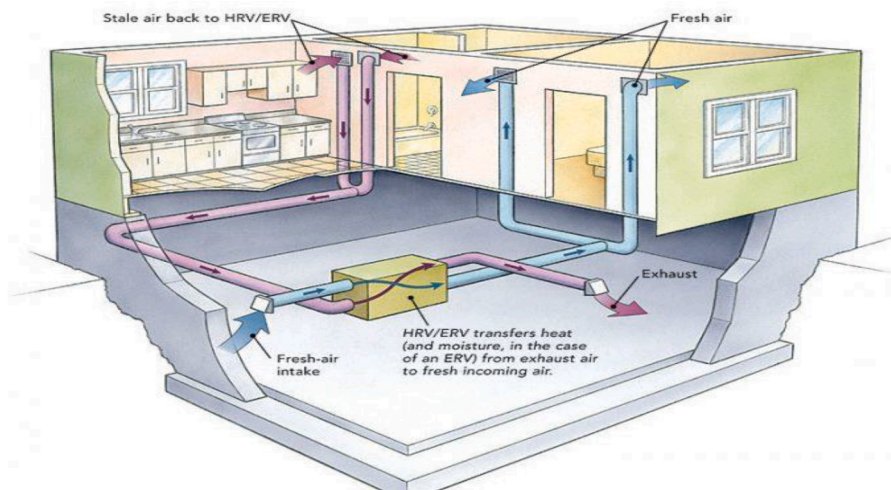


Fig. 37. Technique of ERV with feeding (indoor fresh air) and exhaust air (outdoor air) through ducts.

they have a negative effect on their construction and design before the occurrence of this pandemic.

Coronavirus could disperse around buildings via air conditioning systems or even through draught ducts because a research investigation conducted by scientists discovered traces of COVID-19 in a hospital air

duct of the central air conditioning system (Pung et al., 2020). The results made the scientists believe that the coronavirus infection could spread more rapidly through air-conditioning systems. In Singapore National Center for Infectious Diseases, the results from swab analysis of the three coronavirus patients' rooms indicated that the COVID-19

disease may be more contagious than previously thought because of an air duct connected to patients' rooms (Ong et al., 2020). By investigation, one patient thought to be only suffering from "mild symptoms" was found after the clinical check having traces of the virus. It is evident through investigations and observations that the small spherical droplets carried with infectious viruses are suspended through the air pushed by the air duct networks of the air conditioning systems and deposited after periods of time on the internal surfaces of the air ducts and through the air outlets. During the period from January 26 to February 10, 2020, the global epidemic of coronavirus spread in an air-conditioned restaurant in Guangzhou, China, for three groups of families during the lockdown period for China. The results concluded that the transmission of airborne droplets through the air-conditioning outlets was the cause of infection transmission to the three groups through the conditioned air. The results of the observation showed that 1% of patients with the COVID-19 epidemic did not show symptoms of the infection, while patient B3 had a fever. This provides a potential source of outbreaks among the public (Tong et al., 2020; Chan et al., 2020). Fig. 38 shows a schematic diagram of China's restaurant table arrangement and A/C airflow directions.

To prevent the diffusion of the global epidemic COVID-19 in restaurants, the researchers recommended that temperatures should be monitored and not reduced to an extent that would accelerate the spread of the coronavirus whilst the distance between tables should increase and ventilation should be improved as much as possible (Lu et al., 2020). It is standard practice for buildings and transportations to use recycled air through air-conditioning systems. Hence, it is recommended that any ventilation or air conditioning system that operates with the recycling mode now operate on full outdoor air (Wong et al., 2020). In general, the main parameters of indoor comfort/health are: temperature, humidity, air purity, and air velocity. For temperature to be adjusted, ASHRAE and CDC recommend a range of 20–24 °C in winter and 24–27 °C in summer (/Standard 55-2, 2013a). Air conditioning improves air quality using various techniques; the most commonly used being external ventilation and filtration. It is important that there is no feeling of local cooling of the body due to the movement of air caused by air conditioning in the occupied space. The ASHRAE research guidelines indicate that the maximum airspeed in the occupied space is 20 m/s by the room's heating, ventilation, and air conditioning system (/Addendum b to, 2013). The following are important considerations for air distribution that must be taken into account (Lipinski et al., 2020):

- Regular distribution of temperatures and control of the rate of airflow and airspeed (no more than 20 m/s in the building), which avoids the risk of transporting virus-carrying particles from one part of the room to another.
- Consider the amount of airflow with the cooling capacity of the unit (around 5.7–11.3 cubic meter/ton in North America). In addition, the cooling capacity in relation to the air-conditioned space should not be large or small, i.e., calculated correctly.
- The ideal distribution of the renewed air exit position is achieved through a position that ensures good airflow, but it does not blow air directly into the occupied area and guarantee that the air can transport and spread before reaching the inhabited area.

5.2.1. Classification of HVAC systems

In order to consider air-conditioning as a source for transmission of respiratory virus infections that would spread on a large scale (Handling Editor: Adrian C, 2020), air-conditioning will be studied in some detail as follows. Air conditioning systems are generally classified into two sections, as shown in Fig. 39, according to physical configuration to decentralized systems and centralized systems, which are reviewed below.

The fact that most air conditioning systems operate with the return air cycle must be reconsidered in the light of adjusting and controlling the amount of the return air and purifying it at the return point to ensure that the pollutants that carry the virus are removed. On the other hand, it is better to close the point of return air and replace it with opening windows at intervals to obtain fresh air in the case of epidemic coronavirus.

5.2.1.1. Non-centralized air conditioning systems. One of the simplest and cheapest air conditioners and is considered one of the best types because of its feature of renewing the air in an air-conditioned place with the capability of supplying an external air inlet (fresh air) through a controlled air gap. Fig. 40 depicts the room window-type air conditioner components.

The disadvantage of this type in the circumstances of the spread of the COVID-19 is the absence of a filter at the air inlet to control the air quality inside the air-conditioned place. Adding a suitable air filter to this type of air conditioner is a magic solution to beat 98% of airborne air pollutants. The window air conditioner is used on a medium-range due to its various defects of making annoying sounds in the air-conditioned place and the lack of uniform distribution of air in the air-conditioned place (Peter and DeepankarBiswas, 2020). There are many studies dealing with window conditioning (Ramos et al., 2020), but a minority dealt with evaluating the performance of window-type air conditioning in removing fine particles especially the viruses suspended in air such as COVID-19. Henry et al. (2011) carried out studies on 5 air-conditioned places (bedrooms) equipped with window air conditioners and compared the results between the regular nomination and the extra nominations. Fig. 41 presents the air path through the window air conditioner.

The results manifested that the additional filters are 7.6 times more effective than regular filters. The residual and leaked particles remain as a result of their accumulation on the fan and its blades, but with routine and periodic maintenance work, the airborne microbes and bacteria that are deposited on them will be eliminated. Suksuntornsiri et al. (2020) added a high-efficiency air filter on three different stages; i.e., normal, partial and full filter of a split-wall air conditioner to prevent the loading of indoor air from small particles of PM_{2.5} and PM₁₀ and its effect on the cooling performance of the split type air conditioning unit operating in the Thai climate. The experiments were carried out by testing the conditioning with the following parameters: refrigeration capacity, sensible heat ratio (SHR), and energy efficiency ratio (EER). Fig. 42 illustrates the test rig of the mini-split type air conditioner.

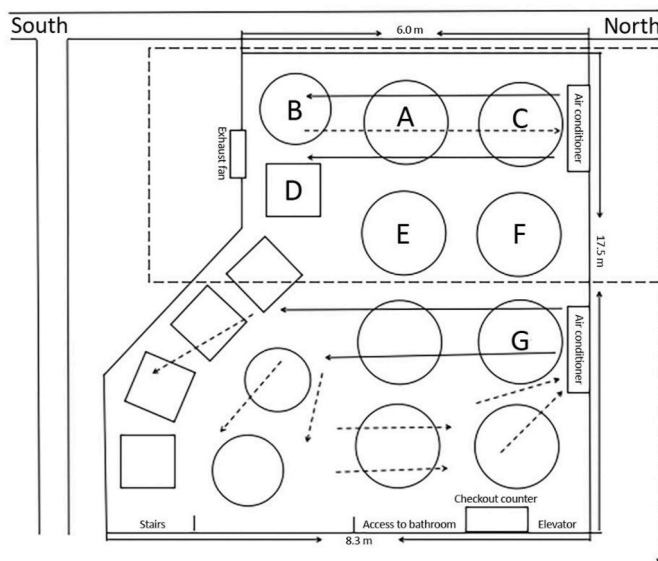


Fig. 38. Schematic plan of the restaurant tables and air conditioners arrangement (Tong et al., 2020; Chan et al., 2020).

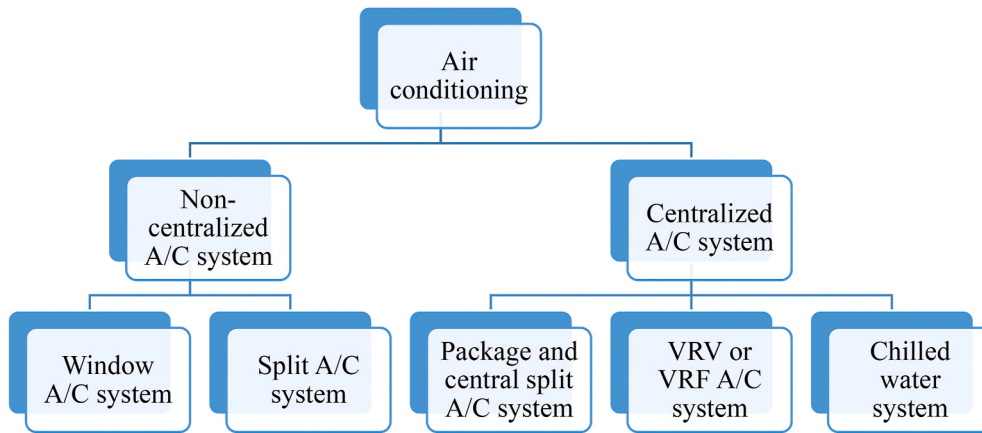


Fig. 39. Physical classifications of air conditioning systems.

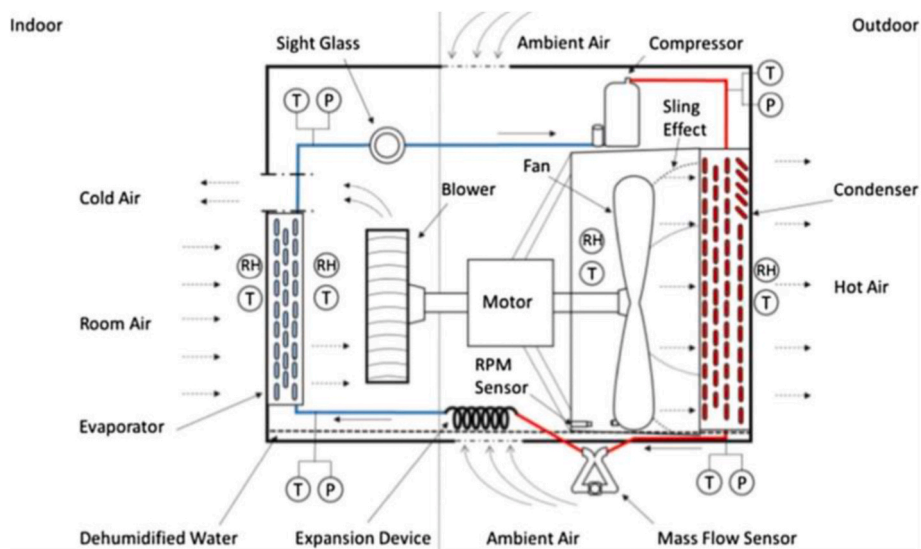


Fig. 40. Window type air conditioner components (Bansal, 2015).

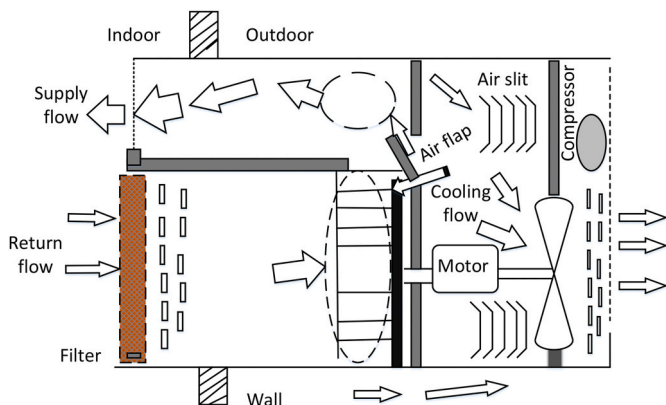


Fig. 41. Air path through a room window type air conditioner.

The results explored that the concentrations of small particles through the air could decrease with a full filter, but with a 16.50% decrease in cooling capacity and a 13.24% decrease in energy efficiency. Furthermore, delaying the operation period to compensate for the decrease in the cooling capacity will lead to an increase in energy consumption. The rate of indoor dehumidification decreased by 42% due to

increased dehumidification.

5.2.1.2. Centralized air conditioning systems. The supply air to the centralized HVAC systems must be cleaned from solid particles, bacteria, viruses, and harmful pollutants before entering the unit of air conditioning (Salem Ahmed and Mimi Elsaid, 2019). Some research proposes solutions to obtain clean fresh air. One of these proposed solutions is to install an ultraviolet unit at the entrance to the HVAC systems which enables indoor air quality (IAQ) by killing various airborne pollutants (Sung and Kato, 2011; Hana Hakim et al., 2019a, 2019b; Hana Hakim et al 2019a; Nakpan et al., 2019; Rudnick et al., 2015; Daniel de Robles and Kramer, 2017; Hana Hakim et al 2019b; Yi et al., 2019; Kanaan, 2019). Various research studies have been carried out experimentally and theoretically on the effect of using UV irradiance in the HVAC system.

The transport mechanism and sedimentation operation of MERS-CoV inside the cabin of the air-conditioned general inpatient ward is studied. It has shown that both air change and exhaust airflow rates have significant effects not only on airflow but also on particle distribution within an area with mechanical ventilation. Additionally, the location of the affected patient inside the wing compartment is critical in determining the risk of infection for other wing occupants. Thus, it is recommended that exhaust grids be provided in close proximity to the patient, preferably above each patient's bed. To achieve infection

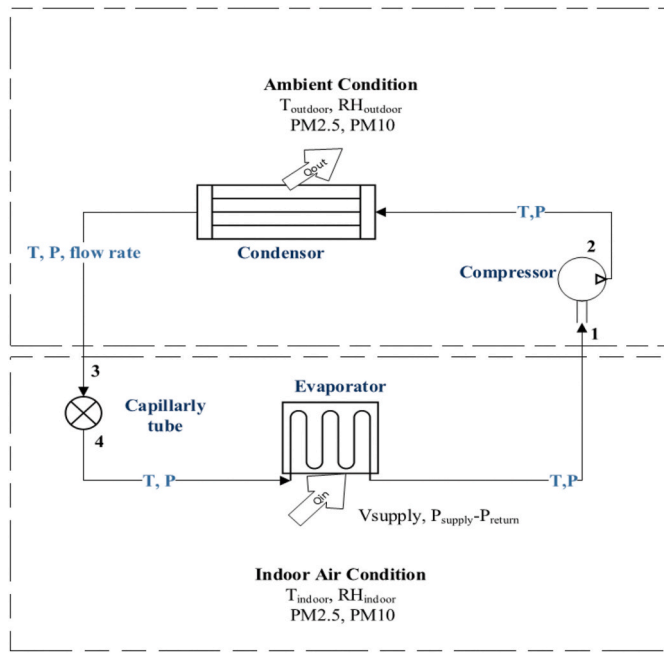


Fig. 42. Mini split air conditioner-Experimental test rig (Suksuntornsiri et al., 2020).

prevention and control, a high exhaust air flow rate is also suggested. Regardless of the ventilation design, all patients and any surfaces in the wing compartment must be cleaned and disinfected regularly and accurately to eliminate microbial contamination. Moreover, it is advised to install UVGI lamps in the wing space to further enhance risk mitigation strategies (Kumar Satheesan, 2020b). Fig. 43 shows an inpatient ward cubicle with patients whereas Fig. 43a presents the case without exhaust grills and Fig. 43b illustrates the construction of local exhaust grills.

It is preferable to provide air handling units with precise air filters in the open air immediately after drawing the external air that filters particles from the outside air, taking into consideration that the size of the coronavirus varies between 60 and 80 nm (Bolashikov and Melikov, 2009).

5.2.2. Methods of modifying HVAC systems for the case of pandemic coronavirus

There are number of means to modify the HVAC system to mitigate and stop the spreading of coronavirus: incorporating a UV lamp, a high-

efficiency filter, and energy recovery ventilation.

5.2.2.1. HVAC provided with UV lamp. Additional advantages can be offered by ultraviolet light by using it in HVAC systems, which include energy efficiency, operating expenses reduction, and creating a better indoor air quality for residents (Zhong et al., 2013). Luongo and Miller (2016) constructed a test unit of two parallel ducts each of them contains a cooling coil providing indoor air sucked by a fan and flowing through a heater and humidifier as shown in Fig. 44. One UVC lamp of 25 W was mounted 254 mm from the coil downstream. The results manifested that under air desiccation conditions with downstream UV irradiance, surface concentrations were higher upstream. Furthermore, it was found that the use of UVG-CC in front of the cooling coil surface ($200 \mu\text{W}/\text{cm}^2$) led to the reduction of the surface microbial loaded by approximately 55% during condensation conditions and prevent bacterial attachment resulting in cohorts of a bacterial issue to become airborne in the direction of the cooling coil. In addition, the air desiccation performed inhibition of superficial and microbial bacterial loading and resulted in mass separation. The air was shown to be treated from viruses and bacteria with UVG-CC with a higher degree of air desiccation system. The proposed unit used indoor lab air from the room as the inlet air. The room supplied 100% outdoor air filtered with MERV 14 filters and maintained with each cooling coil at the condition of 24°C and 44% relative humidity and chilled water at 10°C with flowrates through each coil kept equal to $0.165 \text{ m}^3/\text{s}$. The results showed that under dry surface conditions with downstream UV irradiance, the surface concentrations were higher upstream. UVG-CC reduced the surface microbial loading by 55% on average during condensation conditions and prevented bacterial binding causing groups of bacterial material to move into the air downstream of the cooling coil. Furthermore, it was found that drying inhibited surface bacterial loading and resulted in mass separation but to a lesser extent than treatment with UVG-CC.

Daniel de Robles and Kramer (2017) and Memarzadeh et al. (2010) introduced a review on the UVGI technology. Fig. 45 shows the HVAC system and the position of UVGI lamps in front of the cooling coil to clean bacteria and viruses before entering the conditioned spaces.

Zhang et al. (2020b) have studied the factors that affect the performance of UVC lamps installed in the duct as a means of killing bacteria and viruses. They included airflow velocity, relative humidity (RH), temperature, and duct reflectance. The findings showed that with increasing air velocity and relative humidity, the UV efficacy disinfection decreased. The efficacy of disinfection was lower in a black surface air duct, while the clean air duct was with higher efficacy. To obtain a maximum disinfection efficacy with ultraviolet radiation, temperature settings should be set at $20\text{--}21^\circ\text{C}$ compared to efficacy at low temperatures ($15\text{--}16^\circ\text{C}$) and with high temperature ($25\text{--}26^\circ\text{C}$). Fig. 46 shows a

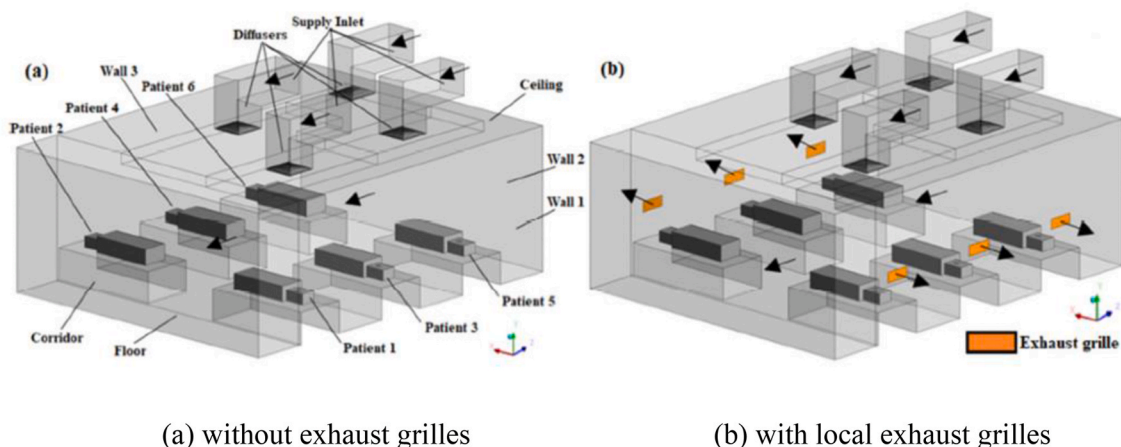


Fig. 43. Inpatient ward cubicle with patients (Kumar Satheesan, 2020b).

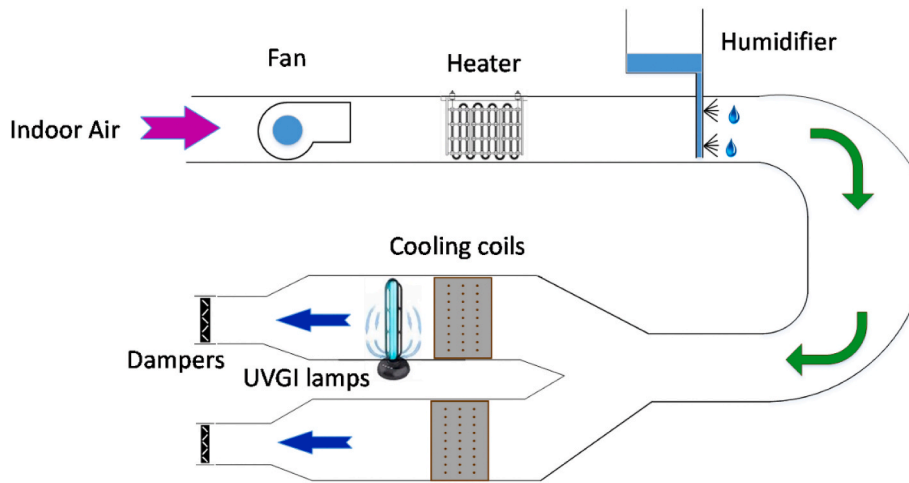


Fig. 44. Schematic of cooling coil for the proposed unit.

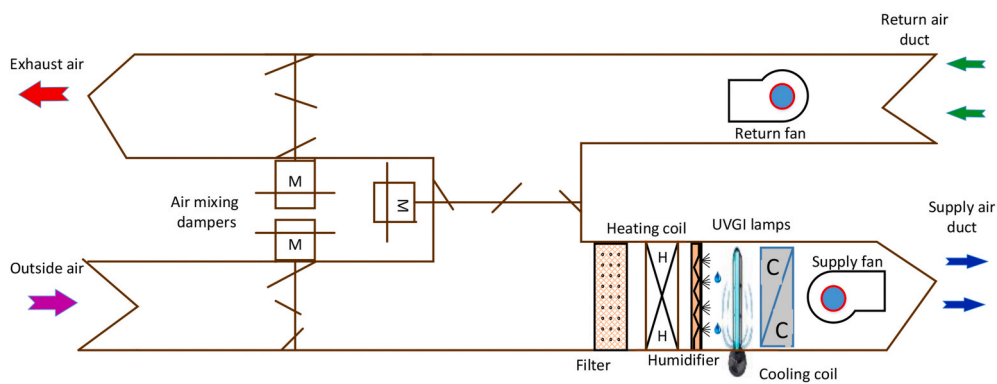


Fig. 45. Schematic diagram of a typical HVAC system with installing of UVGI lamps.

test unit of ventilation duct equipped in the air conditioning lab. The duct is manufactured from galvanized steel with a dimension of 9 m long and a cross-section of 200 mmx 200 mm. The test unit is composed of a

compressor, nebulizer, two HEPA filters, a ceramic heater, a centrifugal fan, a supersonic humidifier, and a UV device. Two HEPA filters, where one is located ahead of the mixing chamber and the second at the outlet

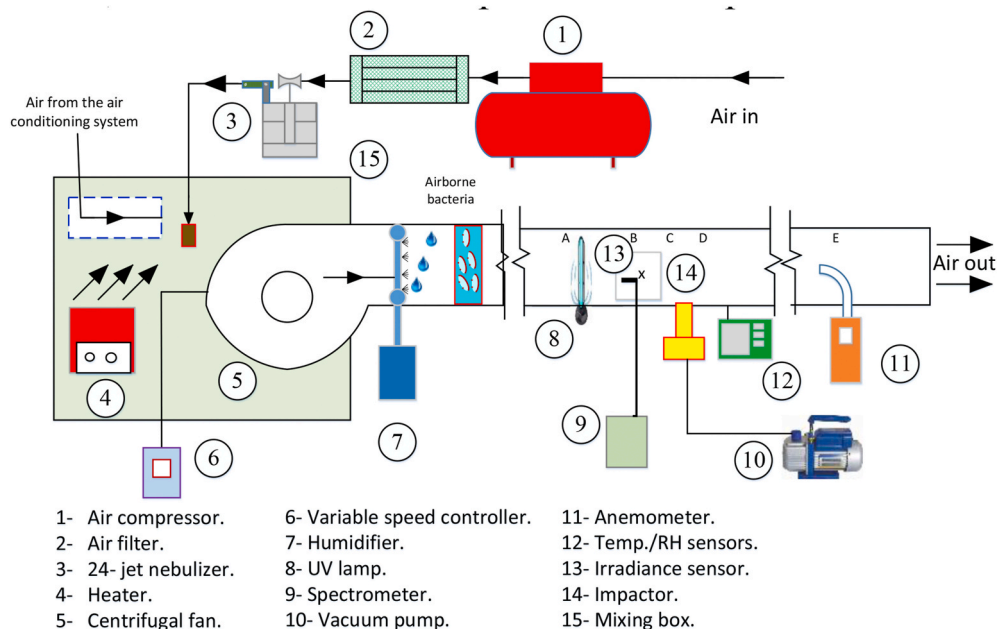


Fig. 46. Schematic of the test rig system.

of the duct, are used to catch the pollutants and particles.

When UVGI units are required to clean the air, as evidenced by all-region risk assessment, those UVGI units must be installed in the HVAC system's exhaust air ducts to supplement HEPA filtration. Fixtures should be fixed to the wall near the ceiling or hung from the ceiling as an overhead air unit or in the return air duct of all rooms (MemarzadehPhD et al., 2010).

5.2.2.2. HVAC provided with high-efficiency filter. Dust samples are collected for 24 air-HVAC systems at different points of the HVAC components to find out the accumulation of fungi on the dust. Then, a statistical analysis is made that gives useful information to control fungus pollution in the air conditioning system. This is achieved by installing high-efficiency air filters which diminish the accumulation of dust in the HVAC system as presented in Fig. 47 (Correia et al., 2020).

5.2.2.3. HVAC provided with energy recovery system (ERV/HRV). Recovery ventilation systems are used to recover around 75% of energy and can be combined with forced-air HVAC systems in the same HVAC duct networking or installed as a stand-alone ventilation system with separate air duct networks away from the central air conditioning network. Indoor air quality could be obtained through integrated energy recovery systems into the air handling unit (AHU) as shown in Fig. 48 (Practical Guidance for Ep, 2020). In the case of an ERV, an exchanger is installed in a system where the outside air portion of the total system airflow is treated by the ERV, but a portion of the air return region is recycled into space as shown in Fig. 48. Turning off the wheel would not then improve the quality of air supply area since the exhaust air transfer rate accompanying the wheel would be small compared to the recycle rate. With the existing epidemic concerns, it is preferred to operate this system as a 100% outdoor unit. To achieve this, the supply and return outdoor air ventilation rates should be increased, the recirculation damper closed and tentatively sealed to reduce leakage, and the system balanced so that Static Pressure Differential is correct for the exchanger type.

HVAC systems operating in a built environment include: the buildings, automobiles, and other indoor settings where most people spend more than 90 percent of their daily lives (Dietz et al., 2019) to provide comfortable, clean and restored air mixed with healthy levels of fresh air, and expel the contaminants outside. There is no doubt that operating and maintaining HVAC systems properly can reduce the spread of viruses. Referring to the American Society of heating, cooling, and air conditioning engineers (ASHRAE), taking into account that critical building systems not only provide thermal comfort but may also reduce infection (/Standard 55-2, 2013a). Healthy levels of humidity are to be maintained between 40 and 60% and temperatures between 20 and 27 °C in order to achieve the thermal comfort conditions according to the ASHRAE code in inhabited places, where all types of air conditioning

systems and equipment are considered necessary. HVAC systems may contribute in reducing SARS-2 spread and survival in the BE area and minimizing the risk of mucous membranes growth. The CDC proposes improving and engineering controls using the building ventilation system including increasing ventilation rates and increasing the percentage of external air circulating through system ("Interim Guidance for Bus, 2020). To secure adequate indoor air quality, a good air conditioning system must include some or all the following (Air conditioning and, 2020; Sloan Brittain et al., 2020):

- It may be appropriate to consider direct outdoor air supply units (DOAS), especially those designed for large quantities of outdoor air to calculate and correct the required amount of ventilation in real-time as increasing the ventilation rate may cause increased load on air conditioners, which may cause them not to work efficiently in this case.
- The filtration process is important to capture the particles that could carry the virus. Therefore, it must be included in the HVAC system with a type of high efficiency of capture.
- Other techniques are available to reduce the presence of pollutants. UV lamps, catalytic oxidation with UV radiation, ionization, plasma, static electricity, activated carbon, and other components can be installed to target VOCs, bacteria, and viruses. Some of these options may be available as an integral part of the HVAC system.

6. Conclusions and guideline recommendations

The spread of health problems inside various buildings in the 1980s led to a review of prevention strategies from the World Health Organization and its emphasis on the importance of indoor air quality and its consideration of the elements that harm human health on the long term. This is because of the rise in temperatures due to global warming, the increase in air pollution rates and its impact on health, and the widespread use of air-conditioners of all kinds, especially if they are used incorrectly.

Accordingly, the need for thoughtful foundations and recommendations to mitigate the severity of the global COVID-19 epidemic emerged as a result of total reliance on air-conditioning and heating systems, which may contribute to the transmission/spread of airborne diseases, as has been proven in the past in describing Japan, Germany and the Diamond Princess Cruise for SARS.

Moreover, the epidemiological characteristics of SARS-CoV-2 are not yet clear, and most recent research has indicated that SARS-CoV-2 spreads faster in winter than in summer, which is an indication of the importance of temperature and humidity in the transmission of COVID-19. The current research lists previous reviews of multiple air pollutants and the various approved and modern methods of purification and filtering methods with an indication of the impact of temperatures and

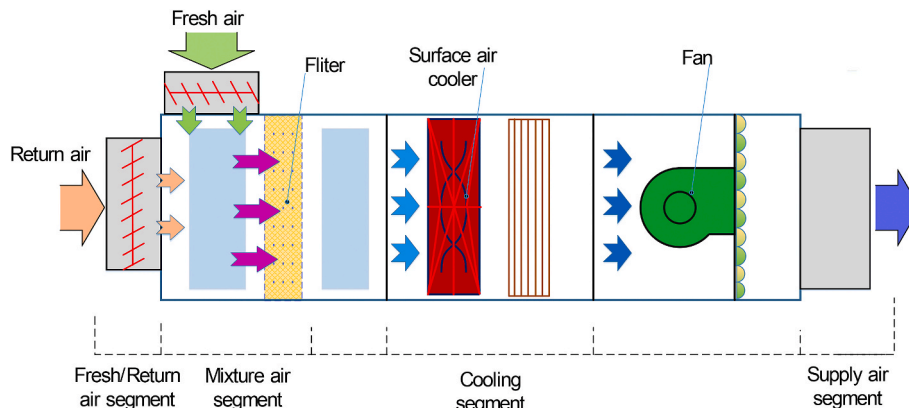


Fig. 47. A schematic diagram of sampling location in the HVAC system.

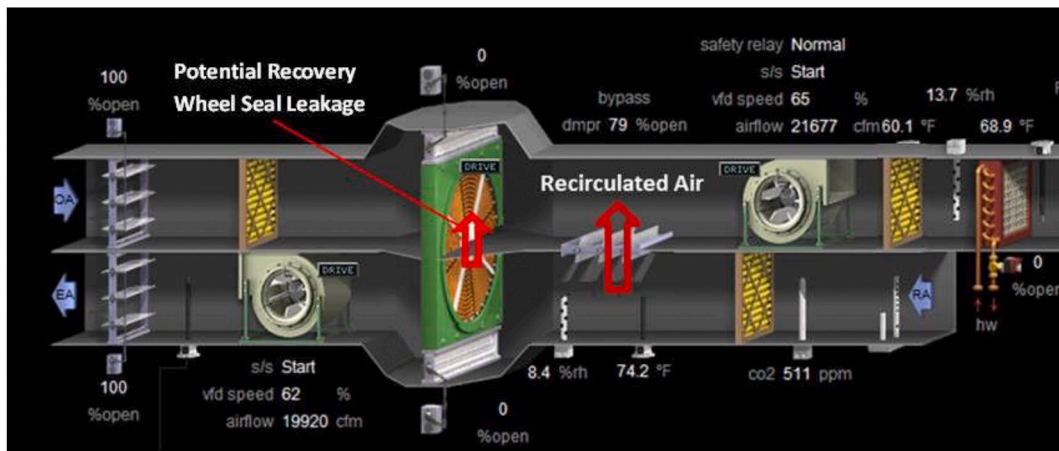


Fig. 48. AHU incorporation with energy recovery exchanger and recirculated air (Practical Guidance for Ep, 2020).

humidity on the spread of the global epidemic of COVID-19; besides, a review of the different air conditioning systems is included to adopt considerations and recommendations to limit and prevent the spread of the global COVID-19 virus as much as possible according to the following guideline recommendations:

1. To meet the needs of indoor air quality, it is necessary to take into account that UVGI is only a primary filtration stage; although it is germicidal, but it is not capable of killing or inactivating infectious microorganisms such as coronavirus.
2. Avoid recirculating air in HVAC systems by closing the return air dampers by diverting the return air of central air conditioning systems to the exhaust air path and feeding 100% of total fresh air.
3. The exhaust air path must be at a height of at least 5 m from the end of the top of the building and the size of the exhaust fans must increase.
4. Installing independent, decentralized air-conditioning units in the isolation rooms for COVID-19 sufferers and closing the central air-conditioning systems in these rooms.
5. HEPA air filters in air conditioners should be replaced by nanofibrous air filters or enhanced electrostatic air filters.
6. Air conditioners that do not have fresh air require opening the windows partially to renew the air in places to provide the largest possible amount of outside air.
7. Negative pressure must be maintained in ventilation systems for isolation rooms for COVID-19 infected patients, as well as in the accompanying bathrooms, while the corridors must be kept at positive pressure.
8. Reducing levels of air pollution inside polluted places and cities, especially industrial ones, by implementing strict, compulsory, and sustainable environmental policies at the international level.
9. Close the path between the corridors and the residents' rooms in central air-conditioning systems in the applications of hospitals and hotels etc., that are designed to draw air from multi-zones air handling units through the suspended ceiling to maintain the negative pressure difference.
10. The amount of exhaust air should be adjusted greater than the supply air through the central A/C systems so that a negative pressure of at least 2.5 Pa (preferably > 5 Pa) is achieved in the zones.
11. The amount of air inside must be changed at least 12 times per hour, with a carbon dioxide level at 400 parts per million to increase the delivery of the fresh air.
12. To quell the COVID-19 virus spreading rate, set the conditioned room temperature between 25 °C and 27 °C while maintaining the relative humidity between 50% and 70%.
13. For treating the air in special cases, the suspended air with bacteria and viruses must be exposed to ultraviolet radiation (15–20 min) and raising its temperature (45 min at 75 °C).
14. Maintaining higher ventilation rates for a longer period with the people staying in the places, whilst set the ventilation rates at a lower level when people are absent at low velocities to reduce the consumed power.
15. Apply MERV 7 as primary filtration and MERV 14 as secondary filters to remove 98% of airborne particles with a diameter of 0.3–1.0 mm.
16. Periodically disinfect HVAC systems, including air ducts, outlets, fans, and air conditioning and heating equipment using chemical disinfection (1% hypochlorite).
17. Avoid the use of circulation fans (flipping fans) in public places inhabited by people. If necessary, the air should be renewed by increasing the flow of outside air (fresh air).
18. Avoid setting air conditioning control systems to low temperatures (below 70 F/21 C) and low humidity settings (less than 40%) to reduce the survival time of SARS-COV-2 in an indoor environment.
19. Commitment to regular maintenance procedures of HVAC equipment and the necessity to wear appropriate personal protective equipment and wrap all damaged materials, such as old filters, and dispose them safely by burning (OSHA 3990–03 2020).
20. Using a strategy of a proper ventilation system, effective air purification technology, humidity regulation, and temperature control that improve indoor air quality and protect against airborne infectious diseases, especially COVID-19.

Novelty statement

The authors confirm that the current research work. "Indoor air quality strategies for air-conditioning and ventilation systems with the spread of the global Coronavirus (COVID-19) epidemic: Improvements and recommendations." made with individual efforts to be important, novel in its presentation of the topic and not published before, and it benefits all humanity as a whole, due to its connection to the topic of the day worldwide (COVID-19).

Declaration of competing interest

The authors emphasize that there are no relationships, interests, or

financial or personal conflicts with individuals or organizations that could negatively affect the current research work. "Indoor Air Quality Strategies for Air-Conditioning and Ventilation Systems with the Spread of the Global Coronavirus (COVID-19) Epidemic: Improvements and Recommendations". In addition, we confirm that this research is carried out by individual efforts to be significant and will benefit all humanity.

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