Impact of Covid-19 on Heating, Ventilation and Air - Conditioning Systems

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Abstract **– People spend much of their lives indoors, so air quality is particularly important to their health, ability to work, and well-being. The COVID -19 pandemic has heightened people's awareness of the importance of maintaining high indoor air quality. Such an emergency has underscored the need for adequate heating, ventilation and air conditioning systems that can provide a good indoor air quality, especially ventilation systems as important players in preventing and reducing the risk of airborne infections. In this paper, we review natural and mechanical ventilation and their roles in dealing with coronavirus, focusing on key factors for healthy indoor air. Two pillars are critical for ventilation: increased air exchange rate and air filtration in ventilation systems.**

Keywords **– ventilation, HVAC systems, indoor air quality, filtration, pandemic.**

1. Introduction

The Covid-19 pandemic has changed the way we think and act in order to maintain a healthy indoor environment by properly designing and deploying heating, ventilation and air conditioning systems (HVAC systems).

Today, it is a challenge for existing HVAC systems to operate successfully in "atypical" situations. A priority for a safe indoor environment is places where many people are present or work together, such as schools, factories, offices, retirement homes, shopping malls, etc. This situation has led to the importance of sensible indoor ventilation strategies.

In order to take measures that will allow HVAC systems to contribute to reducing the possibility of coronavirus infection, it is necessary to know the ways in which the infectious agent is transmitted. Coronavirus is spread mainly by three ways that have been confirmed in numerous scientific studies [1]: from person to person via the droplet route, by the droplets released into the air by the infected person when he or she breathes, talks, coughs, or sneezes on the people in his or her immediate environment, by contact with infected surfaces or objects, and by small particles that spread in the air over longer distances as aerosols.

Numerous scientific studies confirm the transmission of aerosols in the air over longer distances depending on the conditions in the closed space and thus the possibility of infection with the coronavirus within a few hours. [2]. This presents a new challenge, leading to new requirements for existing and future HVAC systems.

HVAC systems are installed to provide comfort conditions (temperature, humidity, air quality) in enclosed spaces (buildings and vehicles), but also to maintain a healthy and safe environment, and under exceptional pandemic conditions with particular emphasis on reducing airborne transmission of infectious aerosols of coronavirus [3]. The pandemic COVID-19 has provided the impetus for engineering solutions for HVAC systems that lead to better living and working conditions for people and open a new vision for the future role of ventilation. Good ventilation system solutions improve the quality of air in closed spaces and help maintain the health of

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the people inside by ensuring a balanced flow of clean air at all times and removing pollutants from the space.

The global COVID -19 pandemic has brought the scientific and professional community together to find solutions to prevent the spread and impact of the coronavirus to protect the health of people around the world. Among other activities to combat the pandemic, the need to maintain a "healthy" indoor environment has been emphasized like never before. Already installed HVAC systems faced new challenges to operate under the "unusual" conditions of a pandemic and to ensure indoor air quality. Therefore, science and experts in the field have come together to find technical solutions and evidence-based practices for a healthy indoor environment where the risk of infection is minimized through the proper use of HVAC systems.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers and the Federation of European Heating, Ventilation, and Air-Conditioning Associations, as respected and important sources of technical and educational information on HVAC system design, installation, and maintenance, have produced documents publishing their research and providing guidelines for dealing with coronavirus in HVAC systems [4], [5], [6]. Among a number of recommendations, they highlight the need for efficient and flexible ventilation, especially in public spaces that can provide adequate quantity and quality of outdoor air, as a basic tool to prevent and reduce the possibility of airborne infection, efficient filtration for better ventilation, and the implementation of emission mitigation systems to reduce possible viral or bacterial infections.

2. Implementation of Measures in Ventilation Systems to Control Coronavirus in Enclosed Spaces

Evidence shows that the spread of coronavirus, i.e. transmission via aerosols, is particularly pronounced in crowded, enclosed spaces with poor ventilation [7]. Ventilation plays an essential role in ensuring good indoor air quality and should meet the prescribed standards ASHRAE 62.1 [8] and EN 16798-1 [9]. Important characteristics of ventilation are the volume flow of external air supplied to the room and the rate of air exchange. Ventilation should be adapted to the actual needs of the users of the enclosed space, but also designed to provide the necessary flexibility.

Increased ventilation of the enclosed space means an increase in the number of air changes per hour, i.e. a greater amount of outside air brought into the enclosed space naturally or by mechanical ventilation. Increased ventilation is always a good solution to ensure a healthy indoor environment, but it is not the only factor, because every enclosed space is different and a detailed analysis is required for an optimal solution. An example of this is the ventilation systems in hospitals, which even before the pandemic with a high capacity and a high ventilation rate to keep pollutant concentrations low and reduce the possibility of transmitting viruses and bacteria in closed spaces. Therefore, if the enclosed space is more intensively ventilated, the virus concentration in the breathing zone of uninfected individuals is lower and the risk of cross-infection is reduced [1].

Optimal ventilation, achieved with a comprehensive and multi-layered strategy, the quality of the environment in the enclosed space improves and, consequently, the well-being and health of the occupants, the transmission of infectious diseases is reduced, and the ability of office workers, children in schools, etc. to work is improved. [10].

2.1. Natural Ventilation

Ventilation can be provided naturally, with infiltration through the building envelope, operable windows, and supply of outside air through air intake grilles. All openings for natural ventilation should be located away from potential sources of pollution to prevent the direct introduction of pollutants.

The amount of natural ventilation depends on weather conditions, the number, location, and size of operable windows and air intake grilles, and also on the users when they need to open the windows or grilles. A general recommendation for enclosed spaces with natural ventilation is to provide a supply of fresh air. An efficient solution is to use automatic systems that control the opening of operable windows and air intake grilles.

Whenever conditions are right, the supply of outside air should be supplemented by frequent ventilation. This should be done by the occupants by occasionally opening the windows, which allows a rapid reduction of the level of pollution in the enclosed space. The ventilation rates that can be achieved through natural ventilation are usually much higher than the ventilation rates of mechanical ventilation systems [11]. The willingness of tenants to adequately ventilate their indoors depends on several factors, such as weather conditions, their habits, etc., but has a significant impact on air quality and the concentration of corona aerosols.

The concentration of CO_2 in the air indicates the intensity of use of the enclosed space, the quality of the indoor air and is a leading indicator of the efficiency of the ventilation system. Therefore, if automated systems are not used to regulate the supply of outdoor air into the enclosed space, install CO_2 sensors or "CO_2 traffic lights" in the occupied area to warn users of insufficient ventilation and remind them to open windows and grilles in time. To maintain indoor air quality, the REHVA recommendation of 800 ppm CO_2 should be maintained to ensure adequate ventilation. The supply of clean indoor air is directly related to occupant health, work ability, and comfort, so energy-saving settings such as timed ventilation should be avoided, especially during pandemic periods. Instead, extending the operating time of ventilation systems should be considered, e.g., before and after the regular period [1].

The spread of coronavirus in different zones/rooms of a building, known as cross-contamination, is a particularly significant problem and is a consequence of the different air pressures in different zones/rooms. Ventilation should be designed to equalize the pressure in the different rooms/zones to minimize airflow between them.

Natural ventilation sometimes does not meet the requirements of clean outdoor air, due to the increase in air pollution in the outdoor environment, and thus the exposure of the room to pollutants introduced by ventilation, which has been confirmed by a number of studies [10]. This shows that it is important to provide clean outdoor air, for which immediate measures must be taken. Under such conditions, outdoor air filtration and/or indoor air purification are required.

One solution is to combine natural ventilation with portable indoor air cleaners. These local filtering devices remove micro-droplets from the air, but their range is usually limited to small areas and they must be placed near the people who are in the indoor [1].

2.2. Mechanical Ventilation Systems

The emergency situation with COVID-19 encouraged the development of ventilation systems (i.e., the introduction of outdoor air into enclosed spaces), particularly in public spaces, schools, and workplaces, as a fundamental means of preventing and reducing the risk of airborne infections.

The performance of ventilation systems is defined as the ability to provide the required air exchange at the right place and time. The ventilation rate should match the actual needs of the ventilated space, which may change over time, so design parameters should provide flexibility and control, especially in the flow and distribution of outdoor air.

On the other hand, in recent years, studies in various EU member states have shown that ventilation systems, although harmonized according to existing regulations, do not always provide the required ventilation performance [12], so additional regulatory guidelines are needed. Following a study, the European Commission has produced a report [4] advocating the improvement of ventilation performance in residential buildings.

In practice, various mechanical ventilation systems are used. Total volume air distribution, especially mixed ventilation, is often used. Mixing ventilation with outside air "dilutes" the contaminants present in the air, so that the clean air supplied mixes with the contaminated and usually warmer air, resulting in a uniform temperature and distribution of the contaminants in the space, Figure 1. Total air volume distribution (TVAD) is inefficient [13] because the clean air is brought into the enclosed space at high velocity through ceiling-mounted diffusers, mixing intensively with the room air so that the air has the same temperature, humidity, and quality at almost all points in the space and arrives as such to the occupants. If pollutants are present in the room, the mixed air also reaches the occupant as polluted. In addition, systems with total outdoor air distribution consume more energy than systems with variable outdoor air flow. Therefore, how the air is distributed in the enclosed space is of particular importance.

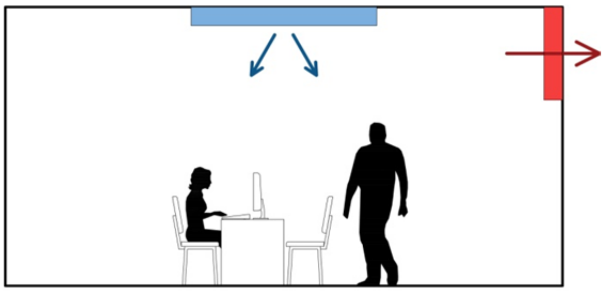

Figure 1. Mixing ventilation

Other types of ventilation systems that are commonly used are displacement ventilation (Figure 2) and diffuse ceiling ventilation. The results of a study [13] that investigated the risks of coronavirus infection for the above mentioned ventilation systems showed that the risk of infection was highest for diffuse ceiling ventilation (DCV) and lowest for displacement ventilation (DV).

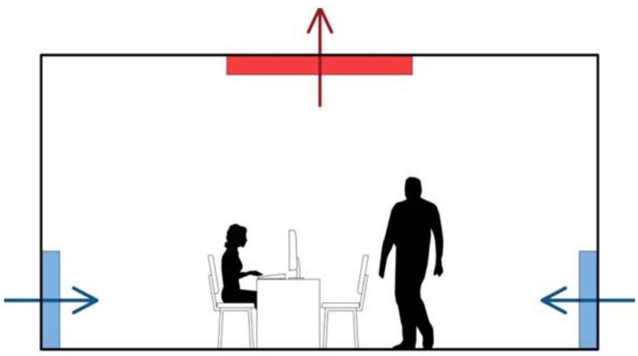

Figure 2. Displacement ventilation

Long-term studies conducted in recent years in various EU member states show that centralized mechanical extract ventilation (MEV) are often used, which only extract exhaust air from exhaust spaces and are controlled by mechanical switches, but very often do not provide the necessary air exchange in ventilated rooms during the heating season [12].

In practice, central ventilation systems are also used to supply conditioned outdoor air to several zones/rooms in the building. In the system, the outside air is filtered and can be heated, cooled, humidified or dehumidified as needed. The different zones of the building should be supplied with an appropriate amount of conditioned air according to the prescribed standards, which changes over time depending on the presence of people in the zones/rooms, which also affects the amount of exhaust air extracted from them. Variable airflow systems provide a quality living environment in the zones/rooms while reducing energy costs.

It is very important to avoid heat recirculation in central ventilation and HVAC systems (especially during a pandemic) to minimize the risk of infection [4]. If centralized ventilation systems are designed without the possibility of minimizing air recirculation, it is recommended to increase the proportion of outdoor air as much as possible.

Occupant targeted ventilation is an advanced distribution of clean outdoor air brought closer to each individual's microenvironment. Occupant targeted ventilation has a non-uniform distribution of outdoor air that is adapted to the needs of the occupants, i.e., a flexible use in which air is brought to where it is needed and as much as is needed, thus avoiding the spread of viruses. Various occupant targeted ventilation have already been implemented and proven successful, but there are also newly developed occupant targeted ventilation [13]. Existing ventilation systems (mixed and displacement ventilation) can be used when implementing some occupant targeted ventilation solutions.

The computational fluid dynamics method was used to simulate an office in which one of the ten employees present is infected with the coronavirus. Several occupant targeted ventilation methods were simulated, including personalized ventilation (Figure 3) as well as the most commonly used ventilation systems: mixed ventilation, displacement ventilation, and diffuse ceiling ventilation [13]. The results showed a significantly lower probability of infection for all occupant targeted ventilations compared to mixed ventilation and diffuse ceiling ventilation.

Simulations of airflow in an enclosed space help find optimal air distribution solutions and achieve the required air quality. Ventilation performance is well demonstrated by simulations using available software such as MATHIS, CONTAM or COMIS multizone modeling software.

When a mechanical ventilation system is used in an enclosed space, there should always be a possibility to provide ventilation by other means, e.g. in case of operational failures. Therefore, it is a good solution to combine mechanical and natural ventilation.

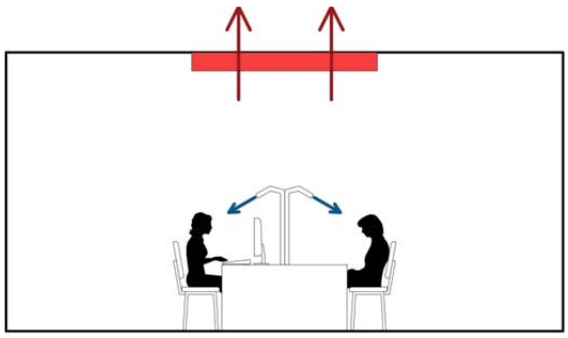

Figure 3. Personalized ventilation

Continuous monitoring of indoor air is actually the control of its various parameters based on measurements of the concentration level of indoor pollutants (usually CO_2) and the risk of condensation, which is usually achieved by installing sensors in the rooms. The signals from the installed sensors enable the optimal operation of the ventilation equipment and the achievement of constant air quality in the indoor, ensuring the required supply air flow and, accordingly, the amount of air that should be removed from the space. If the ventilation rate in the indoors is not measured directly, the measurement of the CO_2 concentration in the air is an indicator of the efficiency of ventilation.

3. Filtering the Air

Filtering the air in the ventilation system is another important way to control the presence of coronavirus in the air and the efficiency of ventilation in indoor spaces. One of the prerequisites for the efficiency of air filtration devices is their ability to adapt to the ventilation rate. The type of filters used in the ventilation system to filter outdoor air depends on the quality of supply air required, but also on the condition of the outdoor air. A proven standard for mechanical ventilation systems is two-stage air filtration with pre-filter ISO ePM10 > 50% (M5) and filter ISO ePM1 > 50%, filter class F7 or F8[5], filters that filter particles from the outside air well [4]. If the outside air contains gaseous impurities, these can be separated in an additional activated carbon filter.

Supply air filters are placed near the outside air intake, and there is usually no need to take additional protective measures when treating the supply air, since it can be assumed that the outside air is virus-free. In situations where the exhaust vent is located near the supply vent (which is less common), contamination of the outside air with viruses is possible. But even in this case, if the usual standard two-stage filtration of the supply air is used, there is usually no need for additional protective measures, since most of the virus particles are in the collection area of the filters [5].

Because indoor air can be infected with viruses, filters are required for the system's exhaust air when it mixes with the supply air, as recirculation air, or when the system has heat recovery. Typically, the filters used to filter return air in HVAC systems are of much lower quality than the filters used to filter outside supply air. Therefore, if the ventilation system uses recirculation air, high quality HEPA filters must be used for the return air to trap and destroy any viruses that may be present in the exhaust and recirculation air.

The use of high-efficiency filters in central HVAC systems significantly reduces airborne infectious particles and their transport from one zone/room to another when the central HVAC system uses heat recovery [14].

Properly designed and maintained ventilation systems are not sources of contamination and do not require changes to normal ventilation duct cleaning and maintenance procedures [15]. If the ventilation system must use recirculated air, which is not recommended during a pandemic, potential virus particles are unlikely to settle in the ventilation ducts because they are carried in the airflow [16].

4. Conclusion

The COVID-19 pandemic has demonstrated as never before the importance of providing safe indoor conditions. Severe Acute Respiratory Syndrome Coronavirus can be transmitted by droplets, by surface transmission, and by long-range airborne (aerosol-based) transmission. The pandemic has encouraged the development of HVAC systems, particularly their flexibility, dynamism, efficiency, and capacity to ensure their operation over a wide range of situations. When properly designed, operated, and maintained, HVAC systems can neutralize and help prevent the spread of coronavirus. Ventilation and filtration are two important pillars in HVAC systems to achieve a high-quality indoor environment and protection against coronavirus. To prevent coronavirus infections, two ventilation strategies are applicable: increasing the ventilation rate and efficiently distributing the supplied air to the user's microenvironment.

Mechanical and/or natural ventilation systems can be used to ventilate enclosed spaces. Properly designed, controlled, and maintained natural ventilation systems provide a good indoor environment and are means of combating the transmission of coronavirus.

The trend toward well-insulated and weather-protected buildings results in lower infiltration rates and a reduced need for ventilation systems. In environments with many people, offices, schools, gymnasiums, theaters, public transportation, etc., ventilation is mandatory, and mechanical ventilation systems should be installed to maintain constant indoor quality, with an optimal number of air exchanges per hour, i.e., with a greater amount of clean outdoor air. In such buildings, natural and mechanical ventilation systems can complement each other.

Optimal mechanical ventilation depends in particular on the efficiency of the solutions for distributing the supply air in the enclosed space, which contribute to minimizing the dispersion of coronavirus particles in the space. When comparing typical distribution systems for several mechanical ventilation systems, the risk of Corona virus infection is highest for diffuse ceiling ventilation and lowest for displacement ventilation.

Occupant targeted ventilation effectively distributes air to the desired location, improving the microenvironment of all occupants and limiting the spread of polluted air from less clean areas to cleaner areas. CFD Analyzes showed a significantly lower likelihood of infection for all occupant targeted ventilations compared to mixing ventilation and diffuse ceiling ventilation.

The proven standard for mechanical ventilation systems with two-stage outdoor air filtration, with prefilter ISO ePM10 > 50% (M5) and fine filter ISO ePM1 > 50%, filter class F7 or F85, provides adequate protection at low concentrations and occasional occurrence of virus particles in outdoor air.

If possible, central heating recirculation should be especially avoided during the pandemic. Where central recirculation cannot be avoided, additional measures are needed to filter exhaust air. The use of high-efficiency HEPA filters for exhaust air in central HVAC systems reduces and almost completely removes airborne infectious particles. When high-efficiency filtration devices are properly selected and used in an enclosed space, they are very effective in reducing infectious aerosols in the space.

The principles of ventilation design to achieve high indoor air quality, in addition to the usual ventilation strategies (determination of air flow based on the enclosed space, the number and type of occupants, a minimum air flow introduced into the space during unoccupied periods, and the possibility of brief forced air flows to dilute and eliminate pollutants caused by various activities in the space), require individual solutions and the mandatory introduction of automation and control of ventilation systems to improve their functionality.

The Covid-19 pandemic has highlighted the need to introduce new standards for ventilation, as it is an important technical tool for protecting people's health indoors, where they spend more than 80% of their time. The future will bring new technical-technological innovations as a result of intensive scientific research, efficient technical solutions that above all guarantee the health of people indoors, but at the same time meet the requirements of energy saving and sustainable energy development.

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