

Operation of air-conditioning equipment and other facilities as SARS-CoV-2 infectious disease control

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The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE)
Ventilation equipment committee

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Introduction

The Ministry of Health, Labour and Welfare's (Japan) Expert Meeting on Novel Coronavirus Infectious Disease Control¹⁾ listed "closed space with poor ventilation" as a space at risk of infection. In response to this, the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan and Architectural Institute of Japan released an emergency presidential discourse, "Role of ventilation in the control of the COVID-19 infection"²⁾, on March 23, 2020, which outlined the characteristics of this virus infection and ventilation methods. Furthermore, Q&A about ventilation, "Role of ventilation in the control of the COVID-19 infection"³⁾, was released on March 30, 2020, which provided a general commentary on ventilation to the public.

Meanwhile, the Ministry of Health, Labour and Welfare released a document entitled "Ventilation to improve closed space with poor ventilation in commercial and other facilities"⁴⁾ and also compiled it as a leaflet, "For managers of commercial and other facilities: ventilation methods to improve closed space with poor ventilation"⁵⁾, on March 30, 2020. Specific ventilation measures are explained in this paper. For mechanical ventilation, conditions should meet the indoor concentration standard of 1000 ppm of CO₂ according to the Act on Maintenance of Sanitation in Buildings, which equals to securing a ventilation volume of 30 m³/h per person. With regard to windows, they must be fully opened for several minutes every 30 min. When these conditions are met, they are not considered as closed spaces with poor ventilation, although it does not necessarily guarantee the prevention of infection. It is recommended to confirm that the required ventilation volume is secured even in commercial and other facilities that do not correspond to specific buildings prescribed under the Act on Maintenance of Sanitation in Buildings. It also states that in the case of insufficient ventilation, the required ventilation volume can be ensured by reducing the number of occupants in the space.

The main infection routes of this virus are reportedly droplet infection and contact infection. Important countermeasures that need to be prioritized are ensuring a minimum interpersonal distance of 1 to 2 m, wearing a mask, frequent hand washing, and disinfecting items and interior surfaces touched by residents. Meanwhile, it is known that the virus from infected individuals may remain active in aerosol in the air for more than 3 h⁶⁾, and that active virus is not easily observed in the air in isolation rooms of patients with frequent ventilation⁷⁾. Based on this knowledge, in addition to following the ventilation procedures recommended by Ministry of Health, Labour and Welfare, any step to maintain ventilation volume as much as possible is expected to further lower the risk of infection.

Building equipment is usually operated with the goal of optimizing occupant comfort, intellectual productivity, and energy-saving performance. However, as a means of SARS-CoV-2 infectious disease control, these goals can be relaxed for some time and operation can be adjusted to reduce the risk of infection. In addition to ventilation equipment, there are issues of the operation of building equipment that is presumably linked to the risk of infection, which will also be discussed below. Similar policy recommendations^{8,9)} have been issued by REHVA (The Federation of European Heating, Ventilation and Air Conditioning Associations) and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

Recent findings on the SARS-CoV-2 infection route and infectivity

From the end of January to February 2020, a study was conducted on the virus activity in isolation rooms of three patients at the COVID-19 outbreak center in Singapore⁷⁾. The isolation rooms were ventilated at a rate of 12 times/h and sterilized daily. Air samples and surface samples were collected from one patient's room before cleaning and from the two other patients' rooms after cleaning. The former patient had symptoms of upper respiratory lesions but no fever or diarrhea, and the latter had moderate symptoms of cough and fever.

Many surface samples collected from the isolation room before cleaning, including those from the bathroom, and the patient's stool samples were positive, containing active virus. The air samples were negative, while the samples from the air exhaust outlets were positive. The samples from the isolation rooms after cleaning were all negative. This study showed the following: (1) interior surfaces of the room of COVID-19 infected patients are extensively contaminated, but the contamination can be removed by appropriate disinfection cleaning; (2) aerosol particles containing the virus travel to the exhaust outlets while maintaining the activity, but sufficient ventilation effectively dilutes the virus concentration in the air; and (3) infected patients' stool may be the infection route.

A research team at NIH (National Institutes of Health) conducted a comparative experiment on the activity maintenance of SARS virus (SARS-CoV-1) and novel coronavirus, SARS-CoV-2 in aerosol particles and on surfaces, such as, plastic, stainless steel, copper, and cardboard⁶⁾. In the form of aerosol particles smaller than 5 μm kept in the air chamber of SARS-CoV-2, the activity was maintained for 3 h, the duration of the experiment, although the infectious titer decreased. The activity was also maintained on stainless steel and plastic for 3 days, on cardboard for less than a day, and on copper for less than 4 h. Overall, the SARS virus and SARS-CoV-2 showed similar characteristics of activity maintenance over time. This study suggests the possibility of COVID-19 infection by aerosol particles containing the virus and contact infection. For SARS virus, an evidence of airborne infection has been reported¹⁰⁾.

In addition, there is another infection risk through the aerosol particles containing viruses of toilet plumes generated in bathroom spaces and drains when flushing the toilet to remove filth containing infectious viruses and microorganisms, which has long been known as an infection route¹¹⁾. The SARS outbreak at Amoy Garden in Hong Kong is considered to have occurred because the infectious aerosol particles generated from flushing infected patients' stool flowed backward in the drainpipe carried by the exhaust ventilation in the room, where the trap seal was broken, spread from indoors to outdoor, and then entered into another house in the air flow¹²⁻¹⁴⁾. In Japan, since proper drain trap depth (sealing depth) is secured and ventilation measures are taken for traps,

the risk of a breach at the drainage pipe which could make a diffusion path for infectious aerosol particles is considered to be low. However, because the active virus has been detected in the COVID-19 infected patients' stool, aerosol particles containing the virus may possibly be generated when flushing the stool of infected patients which could contaminate the bathroom and spread infection by leaking out of the room, although there is no evidence of infection via stool to date.

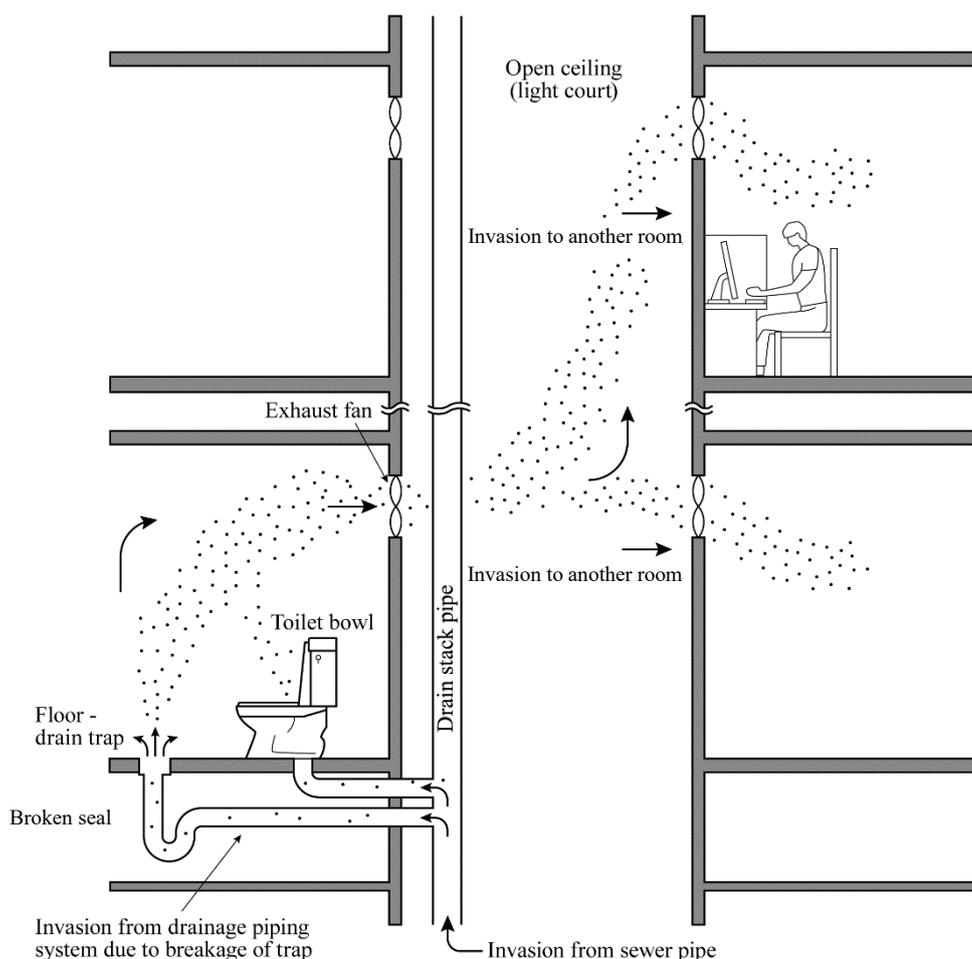


Fig. Infection route at Amoy Garden
(Partially modified from the original¹⁵⁾)

Recommended operation of building equipment

Unit system ventilation (mainly for houses and small buildings)

Rooms without windows, built before July 2003, have been installed with ventilation equipment according to the effective opening area of the room, whereas, all of those built after July 2003 in principle have been installed with ventilation equipment as a Sick House Syndrome countermeasure because of the revision of the Building Standards Act¹⁶⁾. The ventilation equipment for Sick House Syndrome countermeasures must always be on, in principle; however, it can be turned off by holding down a button for long-term absence, such as travel. As one may forget to restart the equipment after returning home, the state of operation must be confirmed.

Generally, ventilation equipment have multiple notches for adjustment of ventilation volume. The legally compliant air flow volume can be realized at a specific notch in most cases. Further adjustments have to be made to operate with a larger air flow volume, in compliance with the ventilation equipment manual. In case of a ventilation fan for exhaust and wall-mounted ventilation equipment, the consideration on the air supply side is often not enough. Therefore, it is recommended to confirm the opening of the small window for air supply and ventilation shutter, inspect for clogging due to dust, and open windows as necessary.

The static total heat exchanger (heat exchange type ventilation fan) has a low risk of virus entry via a heat exchange element, and the risk of cross contamination due to the leak of exhaust air into the fresh air is also as low as approximately 5%. Operation in heat exchange mode, therefore, should have no problem, and it is recommended to select an operation mode with a large effective ventilation volume according to the manual.

In the case when drainage from the indoor unit is treated with a common drainage system while operating the air conditioning, a draft may be created between the rooms or merged drainage system via a drainpipe, risking diffusion of contaminated air. In order to prevent this from occurring, it is effective to install a check valve for air flow in the drainpipe of the indoor unit.

Central air-conditioning system (mainly for large buildings)

As a principle, air-conditioning system should be adjusted to increase the intake of external air volume. In addition, the volume damper openings of the outside air supply fan and exhaust fan should be increased while paying attention to the air balance. In the case where the air flow is inverter-controlled, one should raise the current value and inverter of the supply and exhaust fans and remove the automatic control of the external air volume, fixing the constant air volume damper of the external air system open. If the fan is motor-driven through the pulley, one must exchange it with a large pulley diameter on the motor side. The ventilation volume should be increased by selecting the strong operation mode as long as the generated noise is acceptable. Updating the filter of the outside air system may also increase the air flow volume. Operation should be as close to full outside air operation as possible to minimize returned air volume from indoors and prevent the virus from re-entering the room through the returned air.

In ventilation equipment of buildings with CO₂-concentration control, lowering the indoor CO₂-concentration setting (normally at 1000 ppm) can increase the ventilation volume (it will be maximized with the setting lower than the outside concentration). If there is a mode for outside air cooling, it should be adjusted to preferentially operate outside air cooling by raising the upper limit of the outside air cooling permission conditions and lowering the lower limit. If there is a timer to control this operation, it should be adjusted to extend the operation time longer than the stay in the room; start operation several hours earlier than usual, delay turning off in case of any remaining occupants, and if possible operate continuously for 24 h.

If there is a total heat exchanger, the same measures can be taken for the stationary type as for the individual ventilation system. For the rotary type, if a purge sector is set and the pressure balance is adjusted properly, i.e., return air pressure < supply air pressure, then the risk of virus entry is considered low. Therefore, it is recommended to operate in a mode to have a large effective ventilation volume, while checking/adjusting the operation status as necessary.

Natural ventilation by opening windows

There are not only school classrooms and detached houses but also some recent high-rise buildings in which windows and/or outlet for natural ventilation can be opened in consideration of Business Continuity Plan (BCP) measures for the improvement of energy-saving performance and natural ventilation. These are suggested to be opened in addition to mechanical ventilation as long as it does not cause the draft or thermal discomfort. In particular, opening windows regularly is recommended since securing a draft, that is several tens of air change per hour, will achieve indoor air cleanliness at the level of outside air in a few minutes. (If outside air with three times volume as the room volume is taken in, 95% of the indoor air is replaced). As it is important to secure the wind pressure difference acting on the outlets for realizing a large ventilation volume, opening outlets on different sides of the building is necessary. If there is a door between the outlets, it is necessary to secure an opening area equivalent to the outlet opening surface so that the door will not block the ventilation.

Flushing the toilet with the lid closed and the enforcement of ventilation

When an infected patient defecates in a bathroom and flushes the water to clean the filth, there is a risk of generating aerosol particles containing the active virus. In order to minimize this risk, it is recommended to flush the toilet with the lid closed. In addition, the perfect water seal of the toilet should be checked regularly as when the trap seal is broken, an unusual odor comes out of the drainpipe. The ventilation fan of the bathroom must always be on to prevent contamination of another space by leaked aerosol particles that may possibly cause the infection. If there is a window in the bathroom, it must not be opened because there is a risk of the leakage of the air in the bathroom that contains aerosol particles to the outside when the window is in the upwind side.

Adjustment of air conditioning temperature and humidity

Based on the analysis of the correlation of COVID-19 infectivity by region with climatic conditions, there is a prediction that the spread of the virus may be contained in summer because the infectivity is weakened in high-temperature and high-humidity environments. Consequently, some suggest applying this to air conditioning to control indoor infection. It would certainly be good news if this turns out to be effective, but WHO states “previous evidence shows that COVID-19 can possibly infect any area, including hot and humid areas”¹⁷⁾, and ECDC commented, “high numbers of infections have been observed not only in dry and cold areas but also in tropical areas with high absolute humidity such as Guangxi Zhuang Autonomous Region and Singapore, and there is no evidence so far that SARS-CoV-2 exhibits significant winter seasonality”¹⁸⁾. No clear knowledge has yet been obtained. Nevertheless, in low humidity environments, oral mucosa dryness reportedly reduces the human defense function against infection¹⁹⁾. To avoid this situation, the range of temperature and humidity recommended by the Building Environmental Management and Sanitation Standards (Temperature: 17–28 °C; Relative humidity: 40–70% RH) must be strictly maintained in addition to securing the necessary ventilation volume (30 m³/h per person).

Maintenance of air filter

According to target substance to collect, air filtration is mainly classified into filtration for collecting

gaseous substances and particle substances. In this article, air filter for collecting particle substances (denoted as air filter) will be discussed.

An air filter collects suspended particles near the filter media by mechanisms such as inertial collision, interception, diffusion, and electrostatic attraction. In fact, particle collecting by an air filter is based on one or more of these mechanisms. The mechanisms differ depending on the particle size. The collecting efficiency increases by inertial impaction for large particles and by diffusion for small particles. It is lowest for particles with an approximate size of 0.2 μm . The collection efficiency of air filters for suspended particles by particle size is shown in the table below. In office buildings, medium efficiency air filters (Category E-2 in Table) are typically used, while high efficiency particulate air filters (HEPA: 99.97% or higher particle collection efficiency for particles with the size of 0.3 μm at the rated air flow volume) are used for rooms such as hospital operating rooms that demand high air cleanliness.

The maintenance of the air filter can be performed as usual for full outside air operation. For return air operation, it is recommended to often check the differential pressure of the filter and replace sooner than usual so that the dust collected by the filter will not pass through and enter the room.

Table. Minimum efficiency reporting values (MERVs) and filter efficiencies by particle size

MERV	0.3-1.0 μm	1.0-3.0 μm	3.0-10 μm
Category E-3			
6	—	—	35~50%
7	—	—	50~70%
8	—	—	70~85%
9	—	—	>85%
Category E-2			
10	—	60~65%	>85%
11	—	65~80%	>85%
12	—	80%+	>85%
Category E-1			
13	<75%	>90%	>99%
14	75~85%	>90%	>99%
15	85~95%	>90%	>99%
17	99%	99%	99%

Reference: ANSI/ASHRAE Standard 52.2-2007(ASHRAE 2007).

Effective use of an air purifier

There are two types of air purifiers targeting suspended particles: filtration type and electric dust collection type in which the particles in the air are charged when passing through the ionization section and then collected by the electrostatic precipitator located behind it. This is mainly for commercial use. In recent years, an ion-releasing type air purifier has also been created; however, it is reported that the effect of reducing active virus in the air by this purifier was much lower than any existing filtration technologies²⁰⁾. In this article, filtration-type air purifier is discussed. The Consumer Affairs Agency released “Requests to improve the labeling of products that claim a protective effect against COVID-19 and alerts to the general consumers”²¹⁾ on March 10,

2020, and urgently requested improvements from businesses that displayed such information on negative ion generators and ion air purifiers.

The mechanism of filtration in a filtration-type air purifier is the same as air filter described above. In the case of an air filter equipped in an air conditioner, almost all supplied air is supplied indoors through the air filter with little leakage. In contrast, an air purifier filters suspended particles in the air while circulating the indoor air. Therefore, the purification performance of a filtration-type air purifier depends on not only the filter's collection efficiency but also its air flow volume. The equation below shows the composition of indoor pollutants along with their concentrations in the case of installation of a filtration-type air purifier. The purification performance of an air purifier is determined by $q\eta/V$. Accordingly, it is necessary to determine the number of air purifiers and air flow volume considering the room volume. The use of an air purifier is as effective as auxiliary equipment; however, when the ventilation volume can be secured, it can provide greater reduction of the virus concentration.

$$C = C_0 e^{-\frac{q\eta}{V}t} + \frac{M}{q\eta} \left[1 - e^{-\frac{q\eta}{V}t} \right]$$

M : Indoor pollutant generation [mg/h] or [1/h]

V : Room volume [m³]

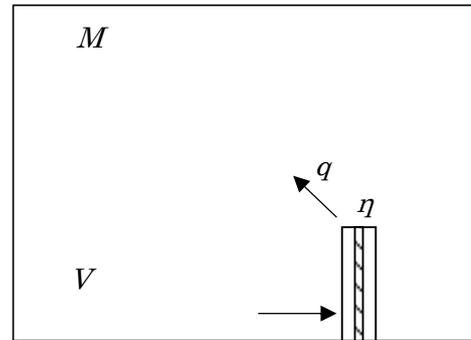
C : Indoor pollutant concentration [mg/m³] or [1/m³]

C_0 : Initial indoor pollutant concentration [mg/m³] or [1/m³]

η : Air purifier collection efficiency [-]

t : Elapsed time [h]

q : Air purifier air flow volume [m³/h]



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