Pandemic-ready airflow control system for hospitals

Masaya Ishihara
Kyoichiro Sakuyama

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In response to the need to accept contagious patients while providing countermeasures for airborne infection in a situation such as a pandemic, we propose a method to change the use of a general hospital room to a temporary infectious disease room by switching the air conditioning equipment to “pandemic mode.” We discuss points to note for the construction of an airflow and room pressure control system that can play an important role in airborne infection countermeasures. In addition, we note the features of a venturi valve developed and manufactured by our company.

1. Introduction

The novel coronavirus (COVID-19) pandemic has led to wide recognition of the importance to society of protecting health-care professionals from infection and maintaining the medical system. If a pandemic occurs, hospitals must not only reserve beds for contagious patients but also take thorough countermeasures to prevent airborne transmission of the disease. What equipment do hospitals need to prepare for a pandemic? This article introduces an airflow and room pressure control system for air conditioning equipment, which plays a central role in airborne infection countermeasures. The airflow and room pressure control system described below has been used at multiple hospitals in Tokyo for about 10 years and has fulfilled its purpose during the current COVID-19 pandemic.

2. Challenges in a pandemic

2.1 Need for concrete measures to prevent airborne transmission

If a pandemic occurs, hospitals face two challenges: accepting many contagious patients and preventing infection at the hospital. In view of the World Health Organization’s statement on July 9, 2020, that the possibility of the airborne spread of the novel coronavirus cannot be eliminated, thorough countermeasures for airborne transmission as well as for contact and droplet transmission, are required to prevent nosocomial (in-hospital) infection. Concrete measures for buildings and their equipment as well as the use of protective gear, sterilization, and zones are essential to prevent the airborne transmission of diseases, as described in *Guidance for Facilities–Criteria for Medical Institutions Designated for Infectious Disease,* published by Japan’s Ministry of Health, Labour and Welfare (MHLW).[1] Table 1 shows the guidelines for air conditioning and ventilation in infectious disease rooms (rooms in category 1 in the MHLW document). Two important requirements are (1) negative pressure relative to the surroundings in order to contain pathogens and (2) maintenance of sufficient ventilation for quick discharge of pathogens.

2.2 Construction of infectious disease rooms

From the viewpoint of health-care professionals and public health, it would be ideal to have a sufficient number of infectious disease rooms (rooms in category 1) and to implement thorough countermeasures to prevent the spread of airborne diseases in preparation for future pandemics. However, the reality is that it is too costly from the standpoint of hospital management to install and maintain many category 1 infectious disease rooms which in normal times will rarely be used. For buildings and their equipment, what is needed is a system that can respond flexibly to changes in the demand for contagious patient beds.

A hint for solving this problem can be found in *JCI Accreditation Standards for Hospitals*, published by the Joint Commission International (JCI). A patient with an airborne disease should be hospitalized in a negative pressure room. If it is difficult for the hospital to construct negative pressure rooms quickly because of the existing building structure, and isolation is required because of an airborne infectious disease but airborne infection isolation rooms (AIIRs) are not available or are insufficient in number, the hospital should use temporary negative pressure isolation (TNPI), isolating patients in temporary negative pressure rooms. The above-mentioned measures must be taken if many patients could be infected as a result of an outbreak of airborne infectious disease.[2] In other words, the standards suggest that the hospital should make the air pressure negative in rooms normally used for other purposes, and then use them as temporary infectious disease rooms if the number of dedicated infectious disease rooms (rooms in category 1) is insufficient due to a pandemic or other cause.

Table 1. Guidelines for air conditioning and ventilation in infectious disease rooms

	Air pressure compared with adjacent areas	Air conditioning method (100% outdoor air or recirculation)	Ventilation rate (including recirculation)	Minimum total airflow (amount of outdoor air)
Infectious disease room (rooms in category 1)	Negative pressure	- 100% outdoor air is desirable. - HEPA filter is required for recirculation. - Recirculation to other areas is prohibited.	At least 12 air changes/hour (HEPA filter is required for recirculation.)	At least 2 air changes/hour

The authors created table 1 based on *Guidance for Facilities–Criteria for Medical Institutions Designated for Infectious Disease.*

3. Switching air conditioning facilities to pandemic mode

3.1 Countermeasures for airborne infection in rooms

What we call “pandemic mode” has begun to be used for air conditioning facilities as a specific way of solving the challenges described in the previous section. As shown in figure 1, this is a method to make the air pressure negative and increase the ventilation in general hospital rooms in order to use them as temporary infectious disease rooms in a pandemic. This method allows the hospital to flexibly respond to changes in the demand for beds for contagious patients.

3.2 Countermeasures for airborne infection in common areas

In pandemic mode, countermeasures to prevent airborne transmission of disease are taken in common areas, such as hallways outside the ward and elevator hallways, as well as in rooms and wards. Figure 2 illustrates room pressure and airflow direction in each room in pandemic mode. A unidirectional inward airflow from the common area to the isolation ward area prevents airborne transmission from hospitalized patients to visitors. If an infectious disease is widely spread in the community during a pandemic, hospital visitors could already be infected. In this case, an air-pressure barrier is created by making the pressure at nurses’ stations positive relative to the surroundings, thereby preventing airborne transmission from hospitalized patients and visitors to health-care professionals.

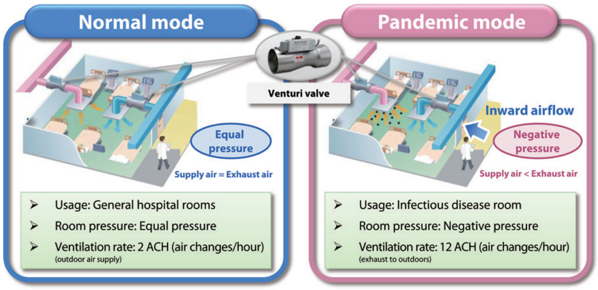


Fig. 1. Conceptual diagram of the transition to pandemic mode

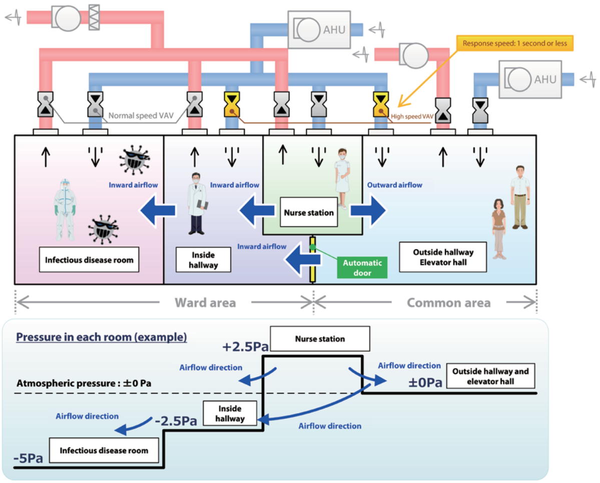


Fig. 2. Example of room pressure and airflow direction in pandemic mode

3.3 Flexible response to changes in demand for contagious patient beds

The area in pandemic mode can be expanded according to the prevalence of contagion in the community. Figure 3 shows an example. At an early stage of an epidemic, the hospital first applies pandemic mode to single (private) rooms. As the epidemic spreads and becomes pervasive, pandemic mode is applied to multi-bed rooms as well to use them as temporary infectious disease rooms, since the hospital is expected to accept as many contagious patients as possible. This method makes it possible to flexibly address changes in the demand for beds for contagious patients and has recently received attention as a rational way of coping with a pandemic while minimizing the decrease in bed occupancy rate.

As part of the infectious disease countermeasures taken in the wake of the H1N1 flu pandemic in 2009, multiple hospitals in Tokyo have already implemented an airflow and room pressure control system that supports this pandemic mode. These hospitals now use this system to significantly increase the number of beds for contagious patients in order to admit and treat COVID-19 patients.

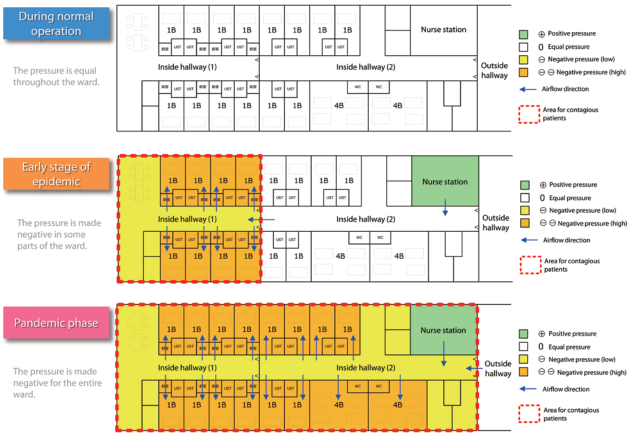


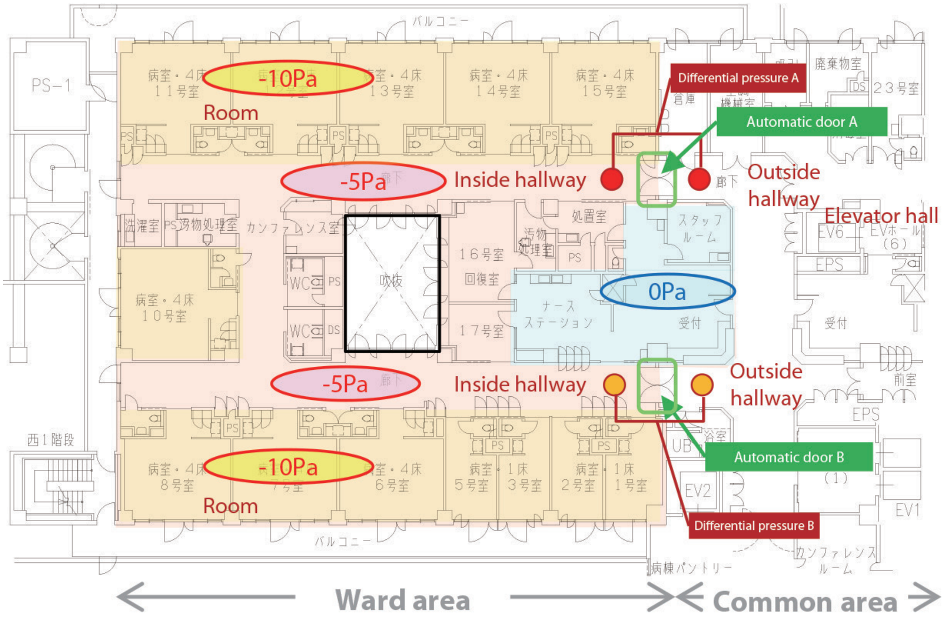
Fig. 3. Example of pandemic mode operation according to the state of infection

3.4 Automatic door interlock control and high-speed VAV units

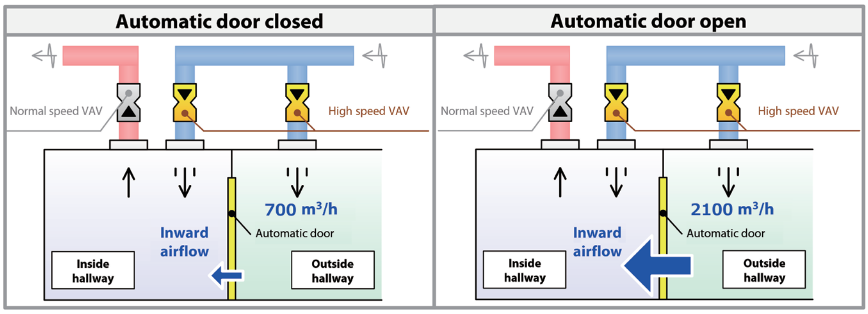
To prevent airborne transmission from ward areas to common areas (see figure 2 in section 3.2), attention to the automatic door at the boundary between these areas is necessary. Doors in this position are often automatic doors, because they are convenient when large equipment such as stretchers or service carts pass through. Therefore, ingenuity is required to prevent the spread of pathogens through natural air diffusion when the automatic door opens. An effective solution is an airflow control method using a high-speed variable air volume (VAV) unit working in conjunction with the automatic door to increase the unidirectional inward airflow from the outside hallway to the inside hallway when the automatic door opens. A high-speed VAV unit with a response speed of less than 1 second is used for this airflow control in order to rapidly respond to the opening and closing of automatic doors.

Figure 4 shows an application example and performance verification result at a hospital in Tokyo.[3] The verification result shown here is the data for a 40 second opening of the automatic door, such as occurs when a hospitalized patient is being transported on a stretcher into the ward. The results show that this airflow control method maintains an inward airflow from the outside hallway to the inside hallway while the automatic door was open.

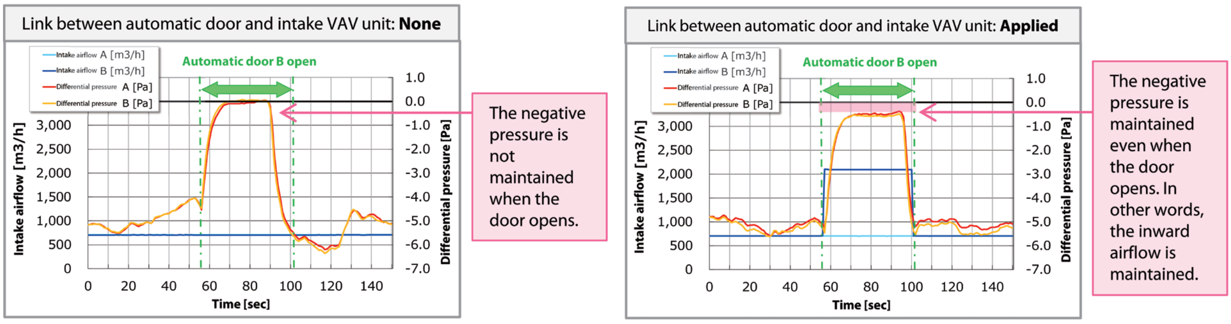
(1) Floor plan of ward and setting of room pressure



(2) Overview of linked automatic door and high speed VAV unit



(3) Performance inspection result at automatic door B



The negative pressure is not maintained when the door opens.

The negative pressure is maintained even when the door opens. In other words, the inward airflow is maintained.

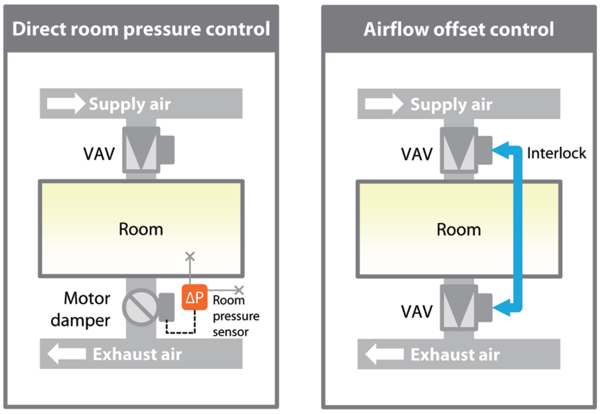
Fig. 4. Example of an automatic door and high-speed VAV unit working in conjunction at a hospital

4. Airflow and room pressure control in hospitals

4.1 Room pressure control method

This article has so far introduced an air conditioning facility control method used to respond to a pandemic. Now we would like to discuss practical points for the construction of an airflow and room pressure control system in a hospital.

It is important to generate a difference in air pressure from adjacent areas to create a proper unidirectional (inward or outward) airflow as a measure against airborne disease transmission in hospitals. If the exhaust airflow is larger than the intake airflow in the room, the room pressure becomes negative relative to the surroundings and inward airflow occurs. If the intake airflow is larger than the exhaust airflow in the room, the room pressure becomes positive relative to the surroundings and outward airflow occurs. Thus, inward airflow in the infectious disease room prevents pathogens from traveling out of the room, and outward airflow at the nurses' station prevents pathogens from entering from outside. The control to create inward or outward airflow by adjusting the intake and exhaust airflow in rooms in this way is called room pressure control. Two room pressure control methods are known, as illustrated in figure 5.



Not suitable for converting a general hospital room into an infectious disease room in pandemic mode.

Optimal for converting a general hospital room into an infectious disease room in pandemic mode.

Fig. 5. Room pressure control methods and their suitability for pandemics

The first method is direct room pressure control. With this method, the intake and exhaust airflow motor dampers and VAV unit are controlled based on the measured room pressure. The second method is airflow offset control. Here, the intake and exhaust airflow is accurately controlled with a VAV or CAV (constant air volume) unit so that the exhaust airflow is larger (or smaller) than the intake airflow, creating an airflow offset (i.e., difference between intake airflow and exhaust airflow) to generate unidirectional inward (or outward) airflow between the surroundings and the room.

4.2 The room pressure control method suitable for hospitals

Which method is most suitable depends on the characteristics and usage of the room and cannot be generalized. However, as explained in the ASHRAE handbook[4] and other documents, the latter method, airflow offset control, is known to be good in terms of stability and reliability, especially for spaces with relatively low airtightness, where doors are frequently opened and closed due to the movement of people, such as a general hospital room. When a room door opens, the differential pressure between the rooms instantaneously becomes zero. As a result, with the former method, direct room pressure control, the motor damper or VAV unit may react excessively to room pressure measurements, making the room pressure and airflow unstable. In addition, the room pressure measurements may be as small as a few Pa in spaces with low airtightness. Therefore, correct control may not be possible with the direct room pressure control method even if the measurement error of the room pressure sensor is very small. As an example of what can go wrong, if the zero-point of the room pressure sensor drifts to the negative side by even a few Pa, the controller may wrongly determine that the pressure is sufficiently negative (when it is actually neutral), decrease the exhaust airflow, and consequently reverse the airflow direction from inward to outward.

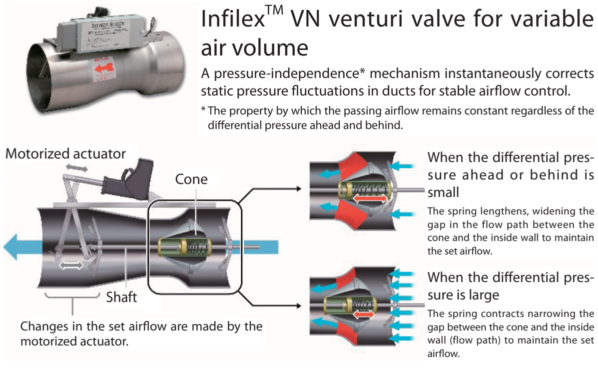
5. Airflow control units (VAV and CAV)

5.1 Requirements for airflow control units

Next, let's consider the selection of airflow control units (VAV and CAV). Dependable VAV and CAV units that accurately and reliably control intake and exhaust airflow are essential for the prevention of airborne transmission of pathogens in hospitals. The pressure loss of air flowing through a duct is proportional to the square of the air speed. For example, if the airflow doubles, the air speed also doubles and the pressure loss quadruples. Therefore, if the airflow changes, for example when pandemic mode is enabled, the pressure distribution fluctuates greatly in the air conditioning ducts. The pressure distribution in the ducts also fluctuates drastically on very windy days due to the wind pressure on the outdoor air intake of the air conditioning units and on the exhaust fan vents. For accurate and reliable airflow control, a mechanism to maintain airflow according to settings without being affected by pressure fluctuations in the ducts (a pressure independence mechanism) is extremely important. To maintain a proper airflow offset and create stable unidirectional airflow to prevent airborne infection, this mechanism must accurately control the intake and exhaust airflow according to the design settings even when the fluctuating duct pressure causes a large fluctuation of differential pressure before and after the VAV or CAV unit.

5.2 Introduction of venturi valves

The venturi valve shown in figure 6 has been developed and manufactured to satisfy these requirements. This valve has an outstanding pressure independence mechanism enabled by the opening of the venturi tube and the expansion and contraction of the spring inside the cone. The valve is perfectly suited for a VAV or CAV unit used in air conditioning facilities as a countermeasure to pandemics. This venturi valve has been employed in medical, research, and other facilities for a long time. More than 25,000 valves have been delivered, a testimony to their performance and reliability.



A pressure-independence* mechanism instantaneously corrects static pressure fluctuations in ducts for stable airflow control.

* The property by which the passing airflow remains constant regardless of the differential pressure ahead and behind.

Changes in the set airflow are made by the motorized actuator.

The spring lengthens, widening the gap in the flow path between the cone and the inside wall to maintain the set airflow.

The spring contracts narrowing the gap between the cone and the inside wall (flow path) to maintain the set airflow.

Fig. 6. Structure and features of venturi valves

5.3 Small valve for small rooms

The smallest venturi valve was previously DN200. However, a smaller size was desired to reduce the space needed for installation, since hospitals have small rooms such as anterooms and changing rooms. We developed a DN150 size venturi valve to meet this need. We currently offer only a CAV model with fixed airflow in size DN150, but also wish to provide a VAV model, the airflow of which is variable, in this size. We aim to reliably control a wider range of airflow with high performance to contribute to countermeasures for airborne infection in more diverse types of rooms by adding small products with low airflow.

6. What we learned from COVID-19

As COVID-19 was spreading on a cruise ship anchored in Yokohama in February of 2020, the authors served as support staff observing the airflow and room pressure control system as pandemic mode was enabled at a hospital in Tokyo. We confirmed that the control system worked without problems and smoothly transitioned to pandemic mode even though more than five years had passed since its installation.

Since the number of contagious patients on the ship was increasing every day at that time, the hospital faced an urgent request to supply more beds for contagious patients as soon as possible. Witnessing the tense atmosphere on the medical front lines drove home to us the need for high-quality equipment that operates accurately and reliably in an emergency to protect the health-care professionals who risk infection and work around the clock to save the lives of contagious patients, and the need to maintain the medical system.

Since the airflow and room pressure control system used in the air conditioning facilities at hospitals is for use in the state of emergency of a pandemic, it is important that it maintains and demonstrates long-term reliable performance.

7. Conclusions

COVID-19 continues to spread at the time of this writing in January of 2021. The government of Japan has again declared a state of emergency to prevent its spread. Nevertheless, the pressure on the medical system due to an increase in contagious patients is reported almost every day. We in the general public are aware that health-care professionals are working harder than ever to treat patients.

Nobody knows when the COVID-19 pandemic will recede and when an outbreak of some new unknown infectious disease will occur. Nevertheless, it is clear that the importance of countermeasures for infectious disease at hospitals will further increase. Out of the entirety of infectious disease countermeasures taken at hospitals, what a measurement and control manufacturer like Azbil can do is limited. However, it is our hope that the products and technologies that we create to the best of our ability, like those introduced in this article, will help to reduce the risk of infection of health-care professionals and others and will help to support hospitals, which play such an important role as one of the foundations of society.

Notes

1. Ministry of Health, Labour and Welfare, *Guidance for Facilities–Criteria for Medical Institutions Designated for Infectious Disease* (in Japanese; 2004).
2. Joint Commission International, *JCI Accreditation Standards for Hospitals* (6th ed., 2017), p. 202.
3. Hiroshi Ida, Tetsushi Shintani, and Masaya Ishihara, "Plan Overview and Inspection Result of Pressure Variation Wards" (in Japanese), *Clean Technology* Vol. 24, No. 1 (2014), pp. 23–26.
4. ASHRAE, *ASHRAE Handbook—HVAC Applications* (2019), p. 17.11.

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Authors
Masaya Ishihara
Workplace Solutions Department
Marketing Headquarters
Building Systems Company
Azbil Corporation

Kyoichiro Sakuyama
Sales Department 1
Sales Business Headquarters
Building Systems Company
Azbil Corporation