Chapter 2
Three Misunderstandings for Design of Negative Pressure Ward

With the severe situation for the appearance of SARS and the fear for the resultant consequence, at the early stage of the outbreak event wards were reconstructed with a simple way. Newly constructed isolation wards were designed according to related literatures issued by CDC in 1994, and the corresponding requirements were elevated blindly. In literatures, the technical measures related to negative pressure isolation ward was inclined to adopt high negative pressure, air-tight door and all fresh air, where it was considered safe only to increase the negative pressure as high as possible, to install air-tight door without infiltration air and to provide all fresh air.

Therefore, three misunderstandings were taken during the design of negative pressure isolation ward at one time, which included high negative pressure, air-tight door and all fresh air. This will cause large amount of waste for investment and energy. Sometimes it even causes severe accident.

2.1 About High Negative Pressure

2.1.1 Effect of Pressure Difference

The so-called high negative pressure means that negative pressure should be kept between isolation ward and corridor or adjacent room. The negative pressure drop should be as high as dozens of Pascal. It is meant to prevent the release of hazardous indoor air from flowing outwards.

Is it really effective to prevent the leakage of airflow outwards? Is it better to adopt higher pressure drop?

The positive pressure inside the ward could be utilized to prevent the invasion of infectious air through the gap into the ward, which is shown in Fig. 2.1. The negative pressure inside the ward could be applied to prevent the release of infectious air through the gap towards outside of the ward, which is shown in Fig. 2.2.

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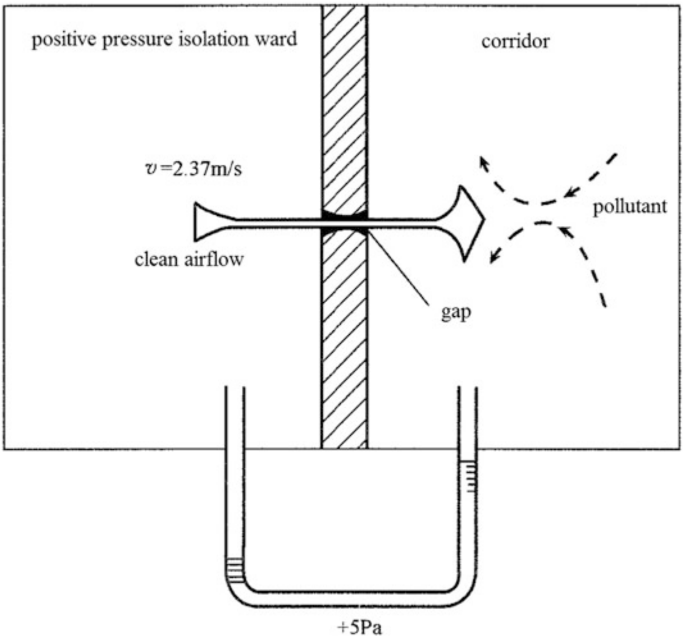


Fig. 2.1 Schematic diagram for prevention of infectious air by positive pressure

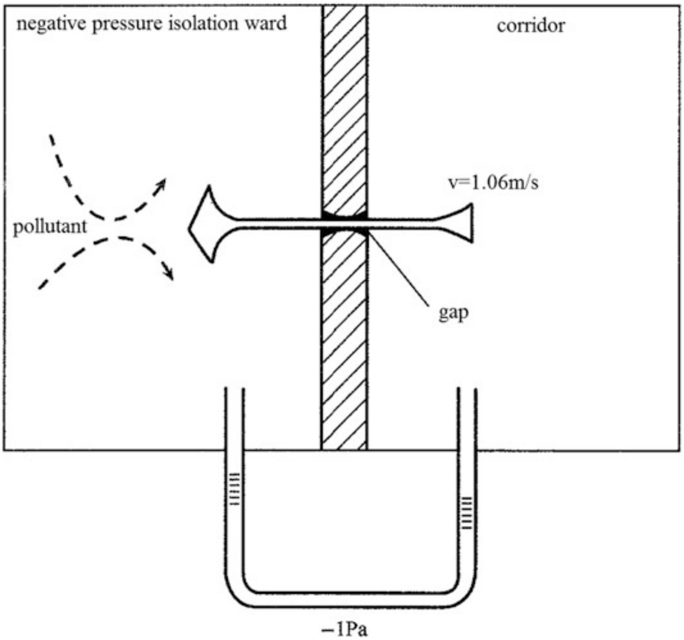


Fig. 2.2 Schematic diagram for prevention of infectious air by negative pressure

The effect of pressure difference on the prevention of leakage though the gap appears only when all the openings between the isolation ward and the adjacent rooms are closed.

Therefore, the pressure difference is only the main measures to realize static isolation.

This characteristic of the pressure difference is based on the time characteristic of the pressure difference.

If the door is open, the pressure difference disappears. In total, the pressure of air at both sides reaches equilibrium.

Figure 2.3 illustrates the experimental result performed by a Japanese scholar [1]. Results showed that for a room with the pressure difference of −15 Pa from the outside, the pressure difference would decrease to 0 within 1 s when the inwardly opened door was open. For outwardly opening door and sliding door were open, the period for this decrease of pressure difference could be prolonged to 2 s. All of them illustrate that there is no effect of pressure difference when door is open.

It was also pointed out in the Handbook of ASHRAE in 1991 that the original pressure difference between two regions would reduce to zero instantaneously when the door or the closed opening between two regions was open [2].

Therefore, it was confirmed in "*Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Facilities*" issued by the Centers for Disease Control and Prevention (CDC) in U.S.A. in 1994 that "the crucial problem is to keep the door and the window between isolation ward and other region closed, except the case when people go inward or outward". It should be noted that here it only mention the state of close, not the sealing condition, which will be explained later.

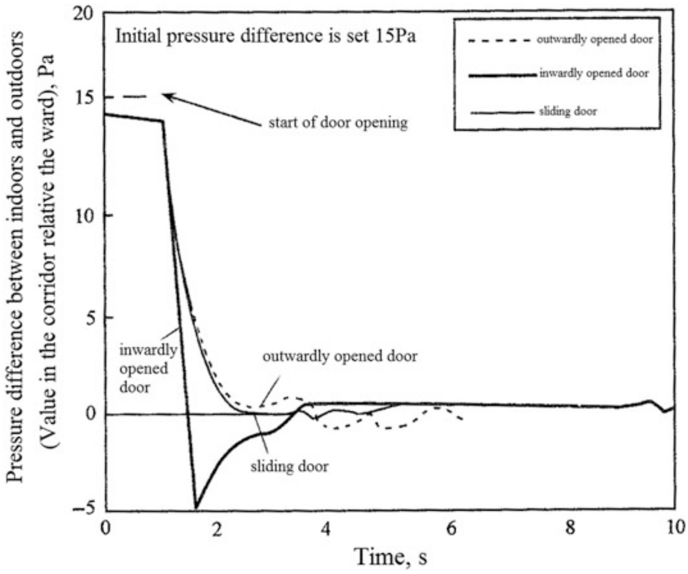


Fig. 2.3 Variation of pressure difference with time during the opening of door

So the main purposed of the pressure drop is only limited to the static state of the closed openings. During the instantaneous moment for dynamic opening of door, the pressure drop is converted into the kinetic energy of airflow through the opening. The magnitude of airflow velocity reflects the ability to prevent the entrance of pollutant, which is not dependent on the magnitude of original pressure difference. For the given flow rate with compensation of pressure difference, the value of airflow velocity is fixed.

In the past, there is an incomplete understanding that for isolation ward, isolation cleanroom and biosafety laboratory, the principle of isolation mainly depended on the effect of gradient of negative pressure (i.e., the negative pressure difference). The negative pressure was considered as the sole measures to prevent the release of pollutant outwards for isolation ward and biosafety laboratory. In the early study, we have investigated and found the instantaneous influence of opening and closing of doors and the entrance and exit of people on the counteracting effect by the pressure difference [3]. Further detailed investigation for the principle of isolation ward was carried out after the outbreak of SARS [4].

2.1.2 Ability to Control Pollution Dispersion by Pressure Difference

In the above-mentioned ASHRAE Handbook, positive and negative pressure could also be considered as the measures to resist other factors. Because of the opening of doors, movement of workers and patients, temperature difference, and the stack effect exaggerated by straight pipeline, elevator shaft and vertical ventilation shaft, it is difficult to control airflow reasonably between rooms. When some factor becomes larger than the actual controlled range, the influence of these factors could be minimized through the modification during the design of positive and negative pressure values in some rooms or regions.

It has been pointed out by author that this incomplete understanding is caused because that they do not understand the invasion or release of pollution and they do not know that the pressure is not the sole factor [3]. This can be analyzed from two aspects as follows.

(1) On the one hand, the air velocity through the door openings by the pressure difference is very small, which could not prevent the outward leakage or invasion of pollutant after the door is open. The flow rate of leakage through gap could be derived further by the air velocity through the gap, i.e.,

$$Q = 3600 \cdot F \cdot v = 3600\mu F\sqrt{\frac{2\Delta P}{\rho}} \tag{2.1}$$

where μ is the flow coefficient. It is usually between 0.3 and 0.5, so we can use 0.4. F is the area of the gap, m^2. ΔP is the pressure difference, Pa. ρ is the air density, which can be assumed 1.2 kg/m^3.

Table 2.1 illustrates the flow rate of leakage for a room with area 15 m^2 under the condition of different pressure drops.

In this room, the dimension of the gap on the air-tight door is 6 m × 0.0005 m, while that on the non air-tight door is 6 m × 0.005 m. The dimension of the gap between the air-tight window and the delivery window is 8 m × 0.0005 m. The size of the gap on the wooden partition board is 40 m × 0.0001 m.

It is shown in Table 2.1 that when the non air-tight door is open, because of the high pressure difference (ΔP = −30 Pa), the air flow rate of leakage in the whole room is converted into the flow rate of entrance air through the gap which is only 0.101 m^3/s. When air-tight door is open, it becomes 0.026 m^3/s, which corresponds to the average air velocity through door opening 0.11 m/s. It is larger than the convection velocity resulting from the temperature difference 0.1 °C by 0.035 m/s, which is very small and will be mentioned later. If the negative pressure difference is −15 Pa, the resultant velocity will be much smaller than the convection velocity.

Therefore, it is essentially a subjective judgment to consider that “for a room with negative pressure when doors are closed, the flow rate during the opening of door mainly depends on the magnitude of negative pressure difference [5]”.

Because of the small flow rate, the effect to prevent pollution dispersion by pressure difference is limited. Therefore, it is also pointed in Ref. [6] by foreign researchers that negative pressure should be kept inside isolation room, but the

Table 2.1 The flow rate of leakage under different pressure drops

Pressure difference	Air velocity through gap	Flow rate of leakage with non air-tight door	Flow rate of leakage with air-tight door	Air velocity through door when non air-tight door is open
ΔP, Pa	$\bar{v}$, m^3/s	Q, m^3/s	Q, m^3/s	$\bar{v}$, m^3/s
1	0.52	0.019	0.006	0.021
2	0.74	0.026	0.007	0.029
3	0.90	0.033	0.009	0.037
4	1.05	0.037	0.010	0.041
8	1.48	0.053	0.014	0.059
10	1.64	0.058	0.015	0.064
15	2.01	0.072	0.019	0.081
20	2.33	0.083	0.022	0.092
25	2.60	0.092	0.024	0.102
30	2.85	0.101	0.026	0.112
35	3.08	0.110	0.028	0.122
40	3.29	0.117	0.030	0.13
45	3.49	0.124	0.032	0.128
50	3.68	0.131	0.035	0.146

magnitude of negative pressure is not important (the same to positive pressure). This is proved in detail by Tables 2.2 and 2.3. For the isolation room with negative pressure, when it becomes positive pressure with magnitude as small as 0.001 Pa (close to 0 Pa), the leakage rate of microbial particles reaches 1.3×10^4CFU/year, and vice versa.

Table 2.4 shows the experimental data when atmospheric dust was applied to study the isolation room by Chinese researchers [7].

In the experiment, the following steps were adopted. At first, full fresh air without air filtration was ventilated through the ward, so that the stable high concentration of dust was reached. Negative pressure difference was kept in ward related to buffer room. Positive or zero pressure difference was maintained in buffer room related to outdoors, so that there was no disturbance of high concentration outdoors on buffer room. At first this value of negative pressure difference was ignored. Although the negative pressure difference was only less than 2 Pa, the concentration inside buffer room was comparable to that of outdoors, which corresponds to condition 1 in Table 4.4.

Table 2.5 shows the experimental data on the influence of the magnitude of the negative pressure difference on the outward leakage rate of pollution during the opening process of doors. This experiment was carried out in the same laboratory [8]. Enough time was provided for the self-purification of the buffer room, so that it reached the designed ISO 6 air cleanliness level. Then the experiment for the opening and closing of doors within 2 s was performed.

Table 2.2 Illustration of pressure difference incapable of preventing outward leakage of pollution

Situation after opening of door in ward	Door opening in ward, air is fully mixed between buffer room and adjacent room	Through the door in buffer room, 1/10 of air in ward exchanges with air in adjacent room	Through the door in buffer room, no air exchange between ward and adjacent room
Outward leakage of microbes through the buffer room immediately, CFU/year	5×10^6	7×10^4	0

Table 2.3 Relationship between outward leakage of pollution from ward and pressure difference

Pressure difference, Pa	CFU/year
Negative pressure indoors, with door closed	0
Positive pressure indoors, with door closed	
0.001	1.3×10^4
0.01	4×10^4
0.1	13×10^4
1	40×10^4
10	130×10^4
0.001 with door open (area 2 m^2)	2600×10^4

Table 2.4 Small pressure difference may cause large pollution

Condition	Pressure difference between ward and buffer room, Pa		Pressure difference between buffer room and outdoors, Pa		Concentration in buffer room, pc/L	
	Before door opening	During door opening	Before door opening	During door opening	Before door opening	Door opening then closed for 12 s
1	−14	0	−1 to −2	No record	17.1	65,366.8
2	−10	0	+1 to −2	0	12.3	1069.8
3	−10	0	+1 to −2	−1	6.4	1350.6

Table 2.5 Relationship between pressure difference and outward leakage rate during door opening

Pressure difference between ward and buffer room, Pa		Pressure difference between buffer room and external room, Pa	Original particle concentration before opening of door (≥ 0.5 μm), pc/L		Particle concentration in leakage airflow after opening of door (≥ 0.5 μm), pc/L			Note
			Ward (A)	Buffer room (C)	Ward	Buffer room (B)		
						Average	Maximum	
One people exits with door opening and closing for 2 s	−31	+6	75,500	76.2	74,100	1258	2120	Max. value appears at the 2nd minute
	−30	+8	59,440	15.2	57,840	1001	1504	Max. value appears at the 1st minute
	−6	+1	104,240	118	100,706	1854	2832	Max. value appears at the 2nd minute
	0	0	107,580	36.9	109,240	2984	4470	Max. value appears at the 1st minute

(continued)

Table 2.5 (continued)

Pressure difference between ward and buffer room, Pa		Pressure difference between buffer room and external room, Pa	Original particle concentration before opening of door (≥0.5 μm), pc/L		Particle concentration in leakage airflow after opening of door (≥0.5 μm), pc/L			Note
			Ward (A)	Buffer room (C)	Ward	Buffer room (B)		
						Average	Maximum	
	0	0	96,190	17.1	98,540	3021	5155	Max. value appears at the 1st minute
No people exits or enters with door opening and closing for 2 s	−30	+8	20,517	41.3	20,024	164	271	Max. value appears at the 1st minute
	−6	+4	9358	14.1	10,823	115	196	Max. value appears at the 1st minute
	0	+5	17,073	5.3	15,371	205	267	Max. value appears at the 1st minute
	0	+5	13,498	–	–	150	202	Max. value appears at the 1st minute

In order to avoid the influence of supply air, indoor vortex and opening/closing of doors on the measurement of pressure difference, which should be paid attention to especially for small room, exterior hood should be placed at the original test hole and the vent hole should be set beneath the hood, which is shown in Fig. 2.4.

The following conclusions can be obtained from Table 2.5:

(a) As long as the relative pressure difference between the ward and the buffer room is not positive, there is no leakage of pollution outwards to the buffer room under the condition of door closing, even when the pressure difference is

Fig. 2.4 Set of exterior hood around the test hold for measurement of pressure difference. **a** Test hole for measurement of pressure difference. **b** Exterior hood around the test hole

(a) Test hole for measurement of pressure difference

(b) Exterior hood around the test hole

zero. The particle concentration inside the buffer room reached the level comparable with that after self-purification, which was about 0.3% of the concentration in the ward. There was no trend of increase for the particle concentration in the buffer room when the pressure difference is zero. On the contrary, this appears the different trend which was related to the residual influence by door opening, entrance and exit of people.

(b) Under the condition of the same original particle concentration, when the negative pressure difference changed from 0 to −6 Pa, the maximum outward leakage of pollution was converted from 4810 pc/L at 0 Pa to 2832 pc/L at −6 Pa, which was equivalent to the reduction rate of 41%. When the pressure difference changed from 0 to −30 Pa, the reduction rate was 62%. Table 2.6 shows the dimensionless concentration ratio in outward leakage airflow, which was related to the subtraction of the background concentration from the stable concentration in outward leakage airflow. It is shown from Table 2.6 that during the entrance and exit of people, the concentration ratios were

Table 2.6 Relationship between pressure difference and concentration ratio in leakage flow

Pressure difference between ward and buffer room, Pa		Pressure difference between buffer room and exterior space, Pa	Concentration ratio in leakage flow = [concentration in leakage flow (B)-background concentration (C)]/original concentration (A)	
			Based on the average concentration	Based on the maximum concentration
One people exits with door opening and closing for 2 s	−31	+6	0.016	0.027
	−30	+8	0.017	0.025
	−6	+1	0.017	0.026
	0	0	0.027	0.041
	0	0	0.031	0.053
No people exits or enters with door opening and closing for 2 s	−30	+8	0.006	0.011
	−6	+4	0.011	0.019
	0	+5	0.012	0.015
	0	+5	0.011	0.015

Note A, B and C represent the data in Table 2.5

comparable under the pressure difference −6 and −30 Pa. The concentration ratio under the pressure difference −30 Pa was (0.041 + 0.053)/2 = 0.047, while that under 0 Pa was (0.025 + 0.027)/2 = 0.026. The corresponding reduction rate was only 45%, which did not match the variation of pressure difference.

(c) When no people exits or enters with door opening and closing, the difference between the cases 0 and 30 Pa is trivial.

Figure 2.5 vividly shows the relationship between the outward leakage concentration ratio and the pressure difference [9].

If no people enters or exits, the relationship of variation is quite gentle. If people enters or exits, the variation becomes abrupt even when the pressure difference is only less than 6 Pa. This phenomenon is understandable.

The same characteristic appears in the above experiment and the experiment performed by Japanese scholar [1]. In the latter experiment, the operation of addition of 200 g additive was performed in a negative pressure room. After 3 min, it was considered that released particles from operation had been dispersed evenly in the room. Then the particle concentration at the return air opening was measured, until it recovered to the original concentration. Based on the increased concentration value and the flow rate of return air, the released particle number could be obtained. In this experiment, the number of generated particles each time was 2.6×10^8 pc. Then the door was open and closed. Once the door was closed, occupant walked towards the return air opening and measured the particle concentration near the return air opening in the corridor. The method was the same to the above-mentioned one.

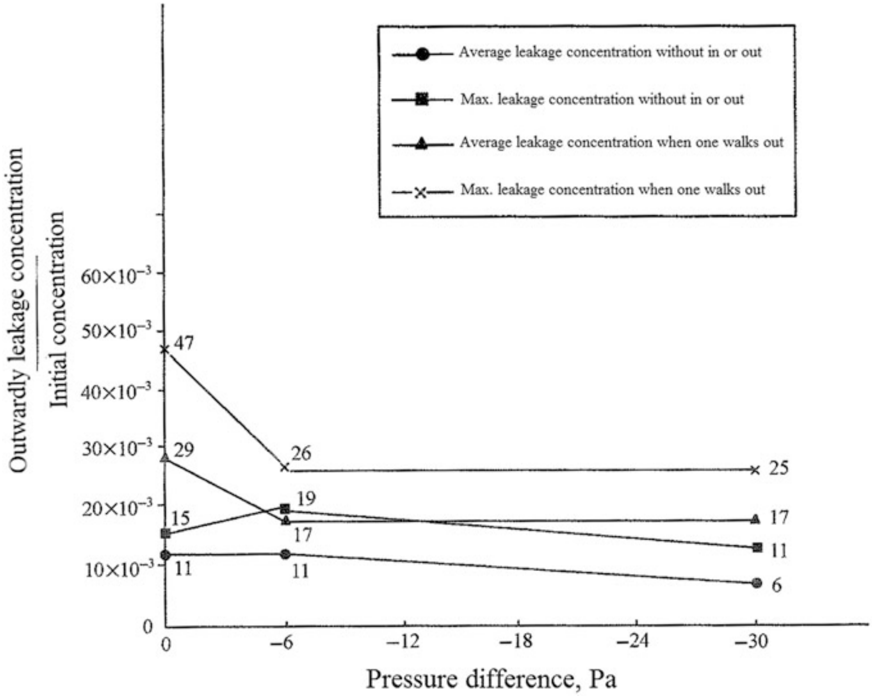


Fig. 2.5 Relationship between outward leakage concentration and pressure difference

The relationship between the pressure difference and the dispersion of pollutant particles is shown in Fig. 2.6.

It is shown in this figure that with the increase of the negative pressure difference value indoors, the number of particles dispersed outwards during opening and closing of doors reduces slightly. The sequence of the number of dispersed particles is that outwardly opening door > inwardly opened door > sliding door.

According to the data provided directly from this literature, when the value of negative pressure difference between indoors and corridor increased from 0 Pa to −30 Pa, the number of particles invading indoors each time during opening and closing of door varied from 4.2×10^6 pc to 1.7×10^6 pc for outwardly opening door, from 1.3×10^6 pc to 1.2×10^6 pc for inwardly opened door, from 0.36×10^6 pc to 0.09×10^6 pc for outwardly opening door, respectively.

It could be estimated from Fig. 2.6 that when the value of negative pressure difference varied from 0 Pa to −6 Pa, the maximum reduction of dispersed particles was about 40%, which is comparable to 41% obtained by our experiment shown in Table 2.5. When the pressure difference changed from 0 Pa to −30 Pa, the reduction of dispersed particles was about 60%, which is comparable to 62% obtained by our experiment shown in Table 2.5. Therefore, it is obvious that no matter whether the pressure difference changes from 0 to −6 Pa, or even −30 Pa, the phenomena of outward leakage of pollution cannot be prevented completely

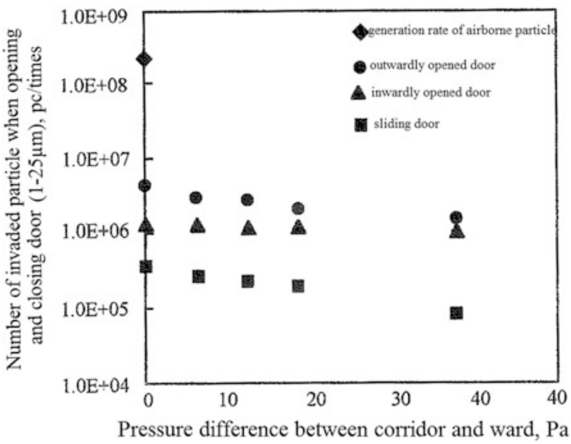


Fig. 2.6 Number of particles invading indoors during opening and closing of door for negative pressure room

during the opening and closing of doors, and the order of magnitude of the pollution is almost the same.

The test with experimental bacteria also proved this conclusion [8], which will be introduced later in the chapter about buffer room. Colored *B. subtilis* Spores were generated in the ward. The CFUs in the ward were measured when the pressure difference between the ward and the exterior buffer room was −5 and 0 Pa, respectively. The CFU in the buffer room was then measured after people left the ward and entered into the buffer room by opening the door for once time. The temperature differences under two pressure difference values were almost the same. Result showed that the CFU was not inversely proportional to the pressure difference. The influence of the pressure difference on CFU was little, which is shown in Table 2.7.

In order to prevent the leakage of experimental bacteria outwards from the buffer room, negative pressure difference should be maintained between buffer room and outer room. There are no experimental bacteria in outer room. This is different from the before-mentioned test with atmospheric dust.

(2) On the other hand, the pressure difference is not the sole factor for the dispersion of pollutant. Temperature difference also exists for such effect. With daily experience, air flows in and out with the effect of temperature difference,

Table 2.7 Performance of outward leakage of pollution by increasing negative pressure value

Temperature difference between ward and buffer room, °C	Pressure difference between ward and buffer room, Pa	Pressure difference between buffer room and outer room, Pa	CFU in ward (Average from 5 samples), CFU/vessel	CFU in buffer room (Average from 5 samples), CFU/vessel	Concentration ratio
+2.2	0	0	752	185	0.25
+2.1	−5	−5	817.8	179	0.22

which cannot be weakened or offset by pressure difference. This will be explained later in detail. Therefore the pressure difference is not the only measures to prevent the invasion or outward leakage of pollution. Therefore, it is not only the pressure difference which plays a role in the isolation principle inside isolation ward, isolation cleanroom and bio-safety laboratory. As a result, it is indeed a misunderstanding that large negative pressure difference value must be maintained for negative pressure isolation purpose.

2.2 About Airproof Gate

It takes for guaranteed that door must be very air-tight in order to prevent the accidental outward leakage of pollutant airflow from indoors. Here we do not assume that the pressure indoors is positive. Even though the pressure difference indoors is positive and the door is air-tight, exchange of pollution airflow cannot be prevented during dynamic condition, such as opening and closing of doors. Of course, in the static condition, i.e. when the door is closed, exchange of airflow can be guaranteed when sealing with good performance is provided on the gap. However, it should be noted that the door of the ward would be open frequently.

2.2.1 Effect of Entrainment by Door

The influence of door closing and opening on transmission of pollutant between indoors and outdoors is explained as follows.

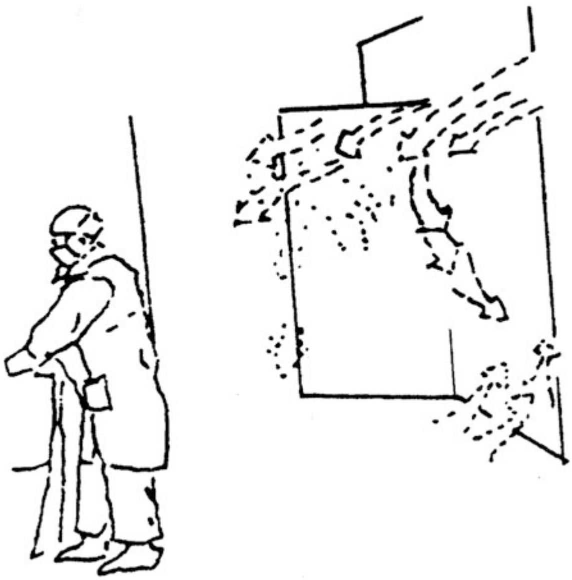
(1) When the pressure indoors is negative and the outwardly opening door is open, air is pushed by the front face of the door, and the negative pressure formed temporarily in the movement region of door may be much lower than the negative pressure indoors. In this case, indoor air is likely to escape outwardly during the opening of doors.

(2) When the pressure indoors is positive and the inwardly opened door is open, air is also pushed by the front face of the door, and the pressure in the movement region of door becomes negative temporarily. In this case, outdoor air may also be sucked inwardly during the opening of doors.

The above-mentioned phenomenon is termed as the entrainment effect by door. In 1961, Wolfe et al. also paid attention to it [10], which is shown in Fig. 2.7. It was pointed out that the quantity of the sucked air by opening of door for once time in room with positive pressure was about 0.17 m^3/s.

Because the negative pressure is formed by the external force from the movement of door opening, there is no air balance between entrance into and exit from

Fig. 2.7 Entrainment effect by opening of door



the room. Therefore it can be assumed that it does not necessarily sound good for the practice to open door outwardly for negative pressure room, or open door inwardly for positive pressure room.

According to our measurement, the air velocity induced by opening of door without occupant passing through is between 0.15 and 0.3 m/s [4].

Suppose the area for door opening reaches 1.5 m^2, the quantity of entrained air is between 0.23 and 0.45 m^3/s, which is slightly larger than that estimated by Wolfe.

For the airflow with such large velocity, the generated airflow through the whole door opening cannot withstand it by the positive pressure from outdoor air or by the negative pressure from exhaust air.

2.2.2 Dynamic Characteristic of Door [1]

The air tightness of door belongs to the static performance of door, which the entrainment performance of door is mainly related to the dynamic characteristic of door.

The dynamic characteristic of door means the feature of counter current, pressure difference, air velocity at the entrance of door, and the transmission of pollutant between indoors and outdoors during the instantaneous opening and closing of door. The counter current is the airflow from negative pressure room to positive pressure room, or the airflow from low pressure room to the high pressure room.

Based on the observatory laboratory with no temperature difference but with pressure difference shown in Fig. 2.8, Japanese scholars performed investigation on the dynamic characteristic on three kinds of doors shown in Fig. 2.9 (Table 2.8).

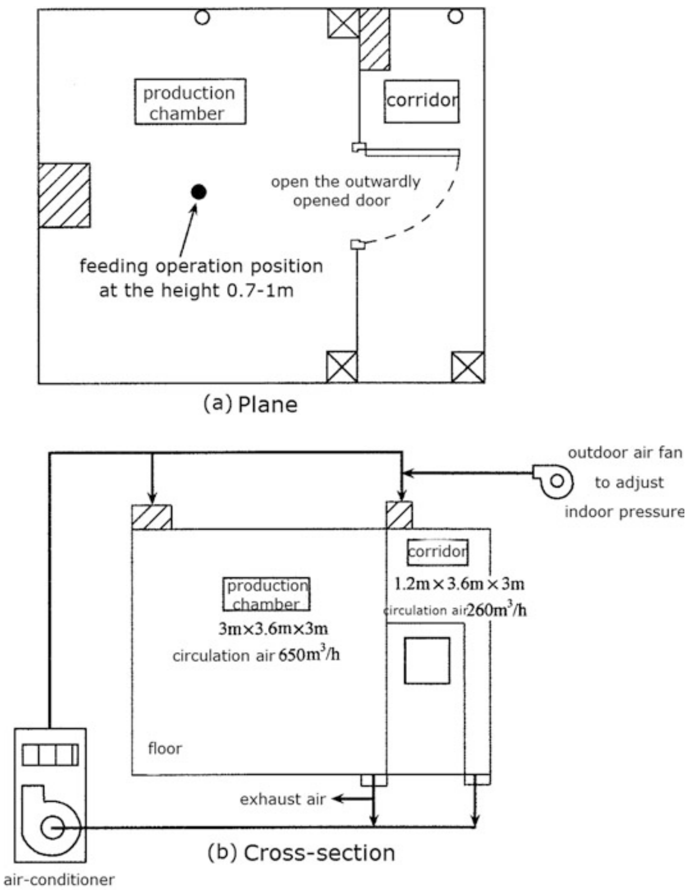


Fig. 2.8 Observatory laboratory for the dynamic characteristic of door (no temperature difference between indoors and outdoors) ● feeding operation position; ○ differential pressure measurement position; ⊠ return air grille; ▨ high efficiency air supply outlet

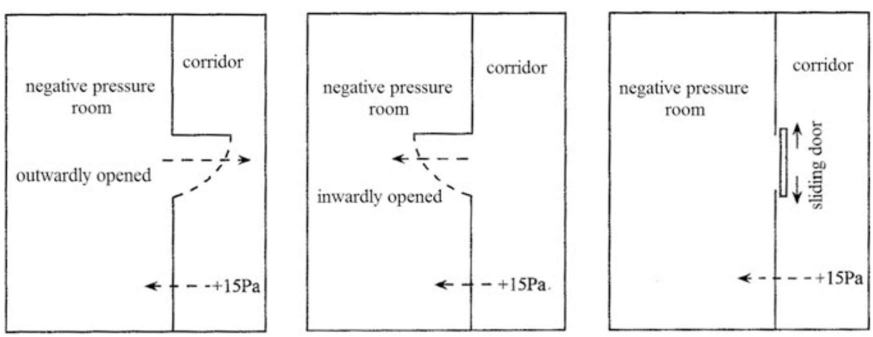


Fig. 2.9 Three kinds of doors

Table 2.8 Situation of visible counter current for three kinds of doors

Door	Opening direction	Stages	ΔP, Pa	Visible counter current
Side hung door	Outwardly	Before door opening During door opening Door opens completely Near door closing fully	15	No Extremely small Slightly weak Strong
	Inwardly	Before door opening During door opening Door opens completely Near door closing fully	15	No Strong No No
	Outwardly	Before door opening During door opening Door opens completely Near door closing fully	0	No Extremely small Slightly weak Slightly strong
Sliding door	Sliding horizontally towards left or right	Various stages	15	Almost invisible

It is shown from the above figure that for the common side hung door, there must exit one phenomenon of strong visible counter current under four stages. This means people are able to see clearly the air flows in the way that it should be prevented. In this case, the isolation performance of air-tight door does not exist. The cost of air-tight door is very high. If interlock function is added, dangerous accident will occur once it is malfunctioned, which has already appeared in the past.

2.2.3 *Effect of Entrainment by Occupant*

The entrainment by occupant is inseparable from the entrainment by door.

It is found from measurement that the air velocity reaches the maximum during the instantaneous period of door opening when occupant walks in or out. This instantaneous air velocity lasts for about 2 s.

Experiment [11] has shown that when occupant walks along the direction of door opening, the air velocity at the entrance is about 0.14–0.20 m/s; when occupant walks against the direction of door opening, the air velocity becomes 0.08–0.15 m/s. Suppose the dimension of occupant is 1.7 m × 0.4 m, the maximum flow rate by occupant entrainment is 0.14 m^3/s.

This phenomenon is termed as the effect of entrainment by occupant. Wolfe has also discovered this, which is shown in Fig. 2.10 [10].

Fig. 2.10 Effect of entrainment by entrance or exit of occupant

2.2.4 Effect of Temperature Difference Between Indoors and Outdoors

It has been introduced in previous chapter on pollution of negative pressure isolation ward that pollution cannot be dispersed outwardly when door is closed. However, door will be opened and closed frequently. During door opening and closing, pollution will be exchanged between indoors and outdoors under the influence of temperature difference.

China Academy of Building Research has performed the specific research on this aspect. Based on the measurement results by different people, the phenomena by temperature difference are described under six conditions. There conditions are shown in Figs. 2.11, 2.12, 2.13, 2.14, 2.15, 2.16, 2.17, 2.18, 2.19, 2.20, 2.21, 2.22, 2.23, 2.24 and 2.25, which include:

$$\Delta t = 0, \quad \Delta P > 0$$
$$\Delta t = 0, \quad \Delta P < 0$$
$$\Delta t > 0, \quad \Delta P > 0$$
$$\Delta t > 0, \quad \Delta P < 0$$
$$\Delta t < 0, \quad \Delta P > 0$$
$$\Delta t < 0, \quad \Delta P < 0$$

The above-mentioned figures are summarized into Table 2.9. Values of Δt and ΔP at the right workshop are used as baselines [4].

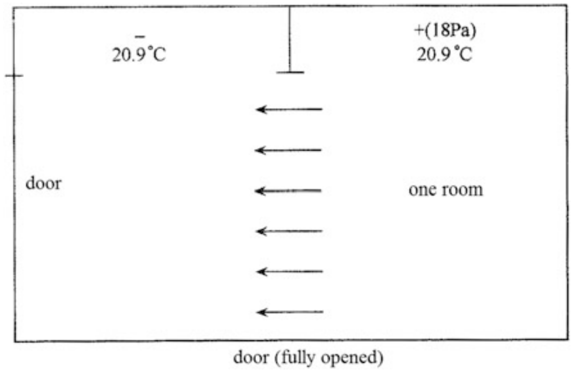


Fig. 2.11 Airflow at the entrance of a room at Guangzhou Ruitai Animal Pharmaceutical Co., Ltd (When door is semi-open, the outwardly airflow at the upper region is much stronger) ($\Delta t = 0$, $\Delta P = +18$ Pa, measured in January 2004)

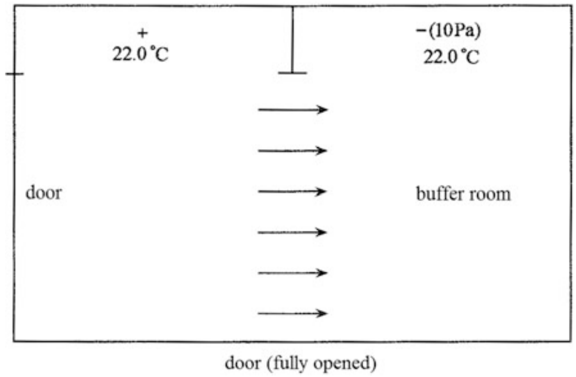


Fig. 2.12 Airflow at the entrance of a buffer room at Liaoning Yikang Biological Co., Ltd ($\Delta t = 0$, $\Delta P = -10$ Pa, measured in May 2004)

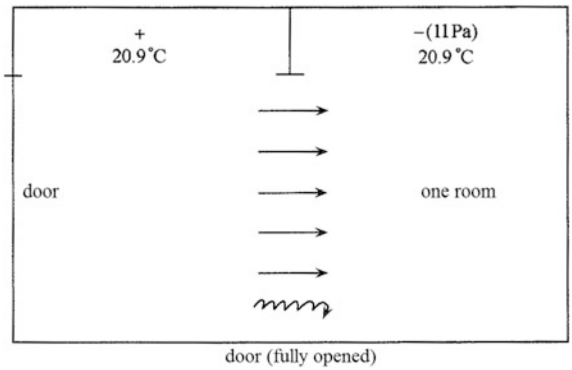


Fig. 2.13 Airflow at the entrance of a room at Guangzhou Ruitai Animal Pharmaceutical Co., Ltd (Air flows inwardly near the floor. Sometimes the flow fluctuates because of the large back flow from floor by large supply air velocity) ($\Delta t = 0$, $\Delta P = -11$ Pa, measured in January 2004)

The following conclusions can be obtained from Table 2.9.

(1) When there is no temperature difference between indoors and outdoors, the direction of airflow complies with the direction of the pressure difference. When the pressure indoors is positive, the air flows outwardly, and vice versa.

Fig. 2.14 Airflow at the entrance of a sterile room at Liaoning Yikang Biological Co., Ltd ($\Delta t = 0$, $\Delta P = -12$ Pa, measured in May 2004)

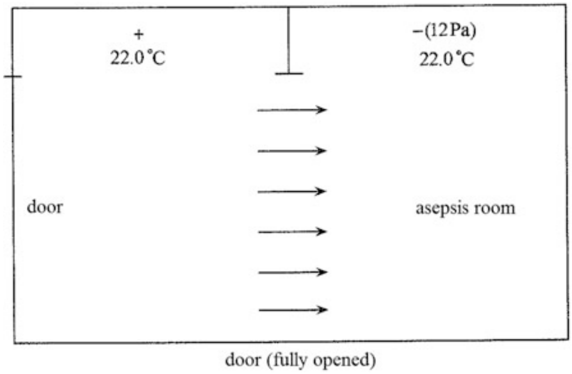


Fig. 2.15 Airflow at the entrance of a room at Guangzhou Ruitai Animal Pharmaceutical Co., Ltd ($\Delta t = 0$, $\Delta P = -50$ Pa, measured in Jan. 2004)

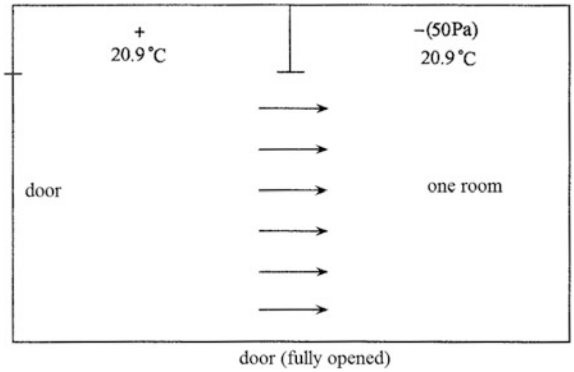
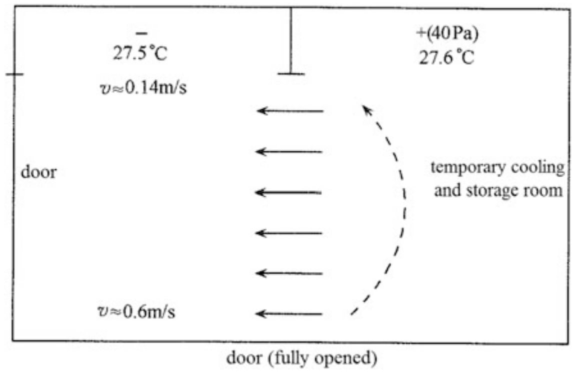


Fig. 2.16 Airflow at the entrance of a refrigeration storage room at Jiangxi Keda Animal Pharmaceutical Co., Ltd (Because the door is close to the return air opening, the airflow velocity at the bottom region is much larger than that at the upper region) ($\Delta t = +0.1$ °C, $\Delta P = +40$ Pa, measured in June 2004)



(2) When there is temperature difference between indoors and outdoors, the direction of airflow mainly complies with the direction of the temperature difference. When the temperature indoors is larger than outdoors, or even the temperature difference is as small as 0.1 °C, the air flows outwardly at the upper region and inwardly at the lower region. For the case with small

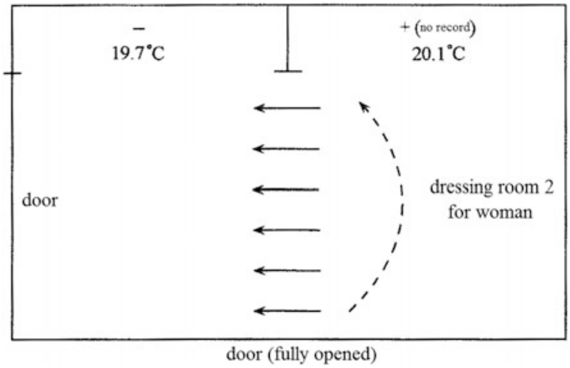


Fig. 2.17 Airflow at the entrance of a Dressing Room 2 for Woman at Hefei Antewei Animal Pharmaceutical Co., Ltd (There is no obvious inward flow at the bottom of the door under the influence of temperature, and it appears gleamingly) (Δt = +0.4 °C, ΔP =>0 Pa, measured in January 2004)

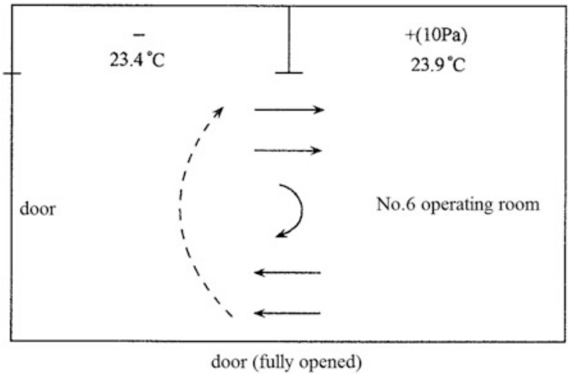


Fig. 2.18 Airflow at the entrance of No. 6 operating room at Chenzhou No. 1 People's Hospital (Δt = +0.5 °C, ΔP = +10 Pa, measured in September 2004, which is explained as sample 8 in Table 2.9)

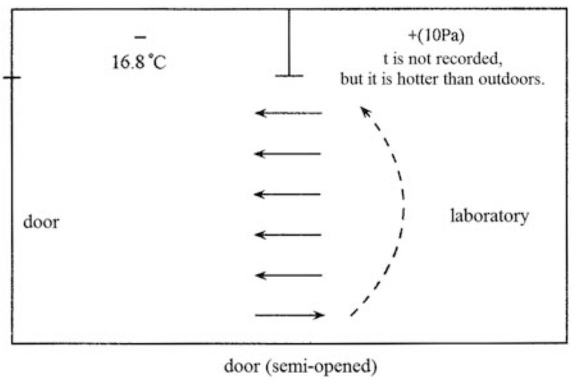


Fig. 2.19 Airflow at the entrance of a multi-functional cleanroom at Institute of Building Environment and Energy Efficiency, China Academy of Building Research (Δt > 0 °C, the temperature indoors was not recorded, ΔP = +10 Pa, measured in December 2004)

temperature difference, the region of convective airflow is small. When the temperature indoors is less than outdoors, or even the temperature difference is as small as −0.1 °C, the air flows inwardly at the upper region and outwardly at the lower region. For the case with small temperature difference, the region of convective airflow is small.

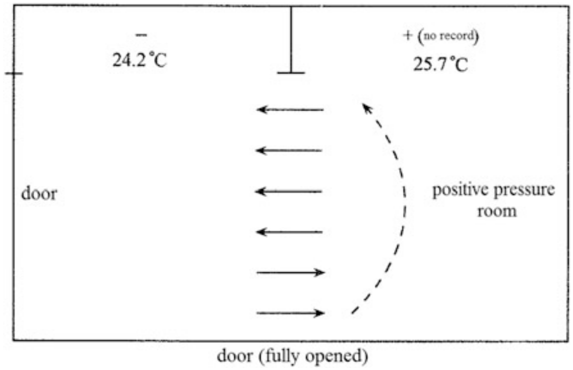


Fig. 2.20 Airflow at the entrance of a positive pressure room at Zhengzhou Modern Pharmaceutical Co., Ltd (Δt = +1.5 °C, ΔP > 0 Pa, the pressure indoors was not recorded, measured in September 2004)

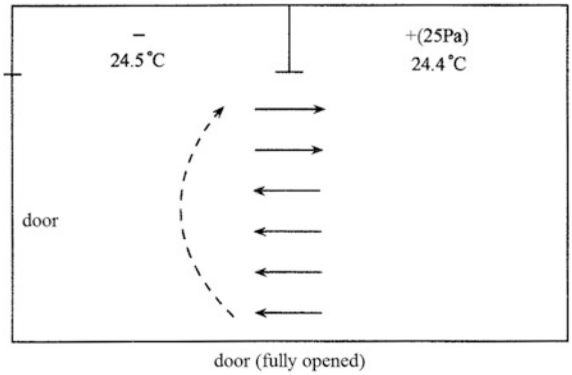


Fig. 2.21 Airflow at the entrance of a Dressing Room 1 at Zhenjiang Victor Pharmaceutical Co., Ltd (Δt = −0.1 °C, ΔP = +25 Pa, measured in May 2004)

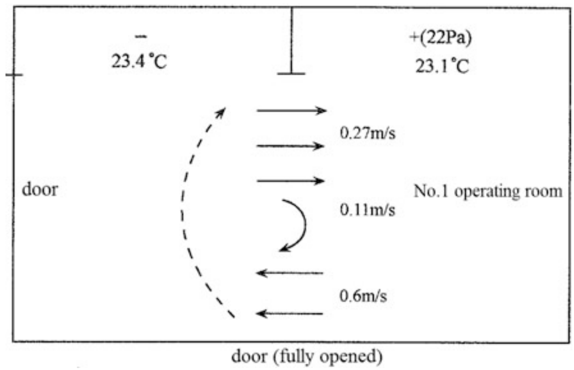


Fig. 2.22 Airflow at the entrance of No. 1 operating room at Chenzhou No. 1 People's Hospital (Δt = −0.3 °C, ΔP = +22 Pa, measured in September 2004)

(3) Under the influence of various factors, the state of the airflow at the middle of the door may be transitional.
(4) When the directions of airflow dominated with temperature difference is consistent with that with pressure difference, the magnitude of the airflow is strengthened.

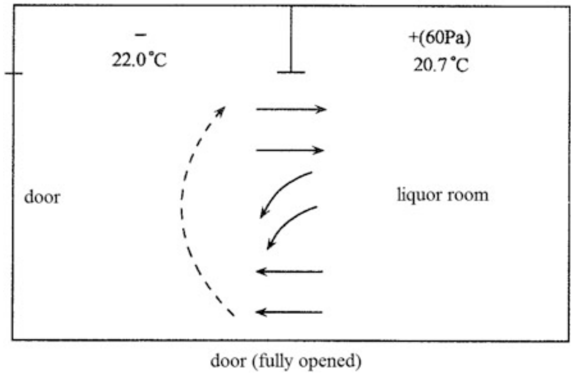


Fig. 2.23 Airflow at the entrance of a confecting room at Hefei Antewei Biological&Pharmaceutical Co., Ltd (Δt = −1.3 °C, ΔP = +60 Pa, measured in January 2004)

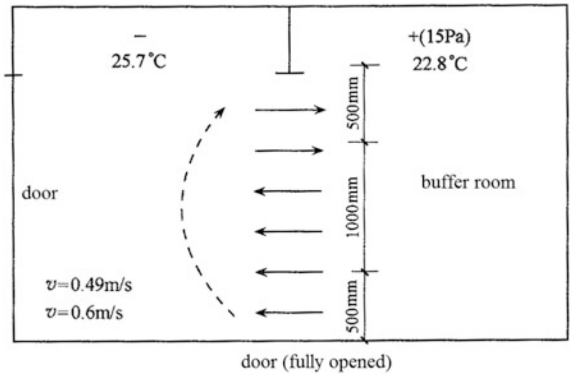


Fig. 2.24 Airflow at the entrance of a buffer room at Shangyu Guobang Animal Pharmaceutical Co., Ltd (Δt = −2.9ºC, ΔP = +15 Pa, measured in June 2004)

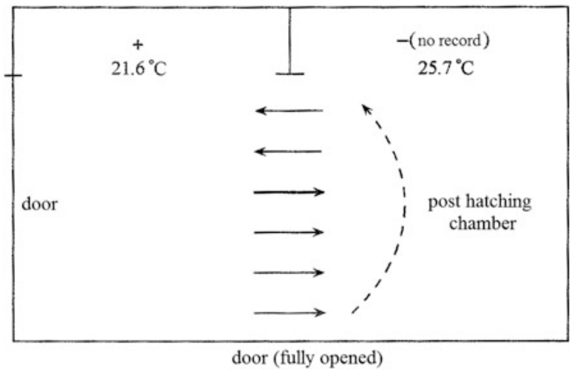


Fig. 2.25 Airflow at the entrance of an incubation room at Zhengzhou Modern Pharmaceutical Co., Ltd (Δt = +4.1 °C, ΔP < 0 Pa, the pressure indoors was not recorded, measured in February 2004)

(5) When the air supply outlet or return air opening is close to the door, or when the air velocity of supply is so large that it impacts the floor, their influence on convective flow by temperature difference is much larger than the influence by pressure difference.

Table 2.9 Influence of temperature difference on air exchange rate at door during full opening

Group	No.	Δt, °C	Convective airflow	ΔP, Pa	Airflow by pressure difference	Actual airflow condition	Note
I		0		>0			
	1	0	No	+18	Outwardly	Completely outward	
II		0		<0			
	2	0	No	−10	Inwardly	Completely inward	Airflow near the floor fluctuates sometimes, this may be caused by back flow exerted by supply air on floor
	3	0		−11			
	4	0		−12			
	5	0		−50			
III		>0		>0			
	6	+0.1		+40		Completely outward	Airflow at the lower region is influenced by the return air opening outdoors, the sucked air outwardly offsets the inward airflow. So there is no visible inward airflow. The inward airflow at lower region of door appears gleamingly
	7	+0.4		>0 (no record)			The value of Δt is slightly larger than the previous case, so the effect is much stronger than the previous case
	8	+0.5	Outwardly at the upper region, while inwardly at the lower region	+10	Outwardly	Inwardly at upper region, rotating in the central region, outwardly at lower region	Maybe the temperatures were recorded oppositely

(continued)

Table 2.9 (continued)

Group	No.	Δt, °C	Convective airflow	ΔP, Pa	Airflow by pressure difference	Actual airflow condition	Note
	9	>0(no record)		+10		Inwardly near floor, outwardly in other regions	Door was semi-open
	10	+1.5		>0 (no record)		Inwardly at upper region, outwardly in other regions	Because Δt is larger than sample 9, the airflow exchange rate is stronger. So the inwardly airflow rate is slightly larger than sample 9
IV		>0		<0			
	11	+4.1	Outwardly at the upper region, while inwardly at the lower region	<0 (no record)	Inwardly	Outwardly at upper region, inwardly in other regions	Because Δt is larger, there is no transitional flow region
V		<0					
	12	−0.1		+25		Inwardly at upper region, outwardly in other regions	
	13	−0.3		+22		Inwardly at upper region, rotating inwardly in the central region, outwardly in other regions	At the lower region, directions of convective flow and flow by pressure difference are the same. The airflow is strengthened
	14	−1.3	Inwardly at the upper region, while outwardly at the lower region	+60	Outwardly	Inwardly at upper region, horizontally or outwardly inclined in the central region, outwardly at lower region	

(continued)

Table 2.9 (continued)

Group	No.	Δt, °C	Convective airflow	ΔP, Pa	Airflow by pressure difference	Actual airflow condition	Note
	15	−2.9		+15		Inwardly at upper region, outwardly in other regions	Because the magnitude of Δt is larger than sample 13, there is no transitional flow in the central region, and the air velocity in lower region is strengthened to be larger
VI		<0		<0			
	16	No case	Outwardly at the upper region, while inwardly at the lower region	No case	Inwardly	No case	No case

2.2.5 Balance Equation of Air Change Rate with Convective Flow by Temperature Difference

With mechanical ventilation system, the balance equation of air change rate is as follows:

$$Q_1 + Q_2 = Q_3 \tag{2.2}$$

or

$$Q_1 = Q_2 + Q_3$$

where Q_1 is the flow rate of the supply air; Q_2 is the flow rate of the leakage air sucked into or exhausted out of the room through the gap or hole of the gate; Q_3 is the flow rate of the return air or that of the exhaust air.

After the door is open, convective flow occurs under the influence of temperature difference. Indoor cold air flows outwardly through the upper region of the door opening, so there must be the same amount of cold air flowing inwardly through the lower region of the door opening. This can provide the balance between the air change rate and the pressure difference. In this case, we obtain:

$$Q_4 = Q_5 \quad (2.3)$$

For pure convective flow by temperature difference, the principle of natural ventilation works. The area of intake flow is considered to be the same as that of the outtake flow. In the middle of the door opening, there is a interface where the interior and exterior pressures are the same, which is termed as the neutral plane. It is shown at the position labeled with 0 in Fig. 2.26.

On the intake and outtake flow planes, the pressure difference caused by the density difference can be expressed as:

$$\Delta P = gh\Delta\rho \,(\text{Pa}) \quad (2.4)$$

where g is the gravitational acceleration, m/s^2; h is the height between centers of intake and outtake planes, m; $h = H/2$, and H is the height of door opening, m; ρ is the density for the intake flow or outtake flow, kg/m^3, which is shown in Table 2.10; $\Delta\rho$ is the density difference of air, kg/m^3.

Because the temperatures of intake and outtake flows are different, the density ρ of hot air is small, so v is large. While the density ρ of cold air is large, so v is small.

Fig. 2.26 Intake and outtake flows through door opening

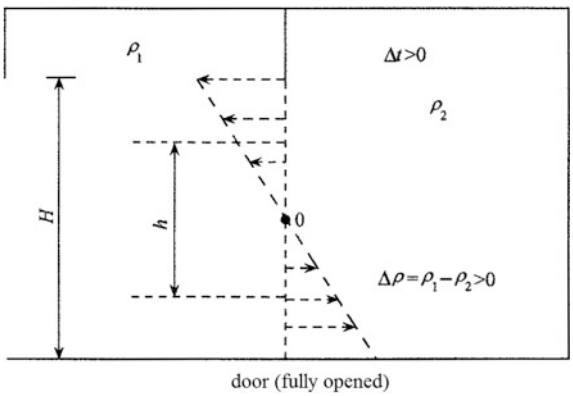


Table 2.10 Density of dry air, kg/m^3

t, °C	Atmospheric pressure, mmHg			
	ρ			
	720	740	760	780
−10	1.271	1.307	1.342	1.377
0	1.225	1.259	1.293	1.727
10	1.182	1.215	1.247	1.280
20	1.141	1.173	1.205	1.237
30	1.104	1.134	1.165	1.196
40	1.069	1.098	1.128	1.158

It is shown from Table 2.10 that under the normal atmospheric pressure, when the temperature is within the range 10–30 °C and Δt = 1 °C, $\Delta\rho$ = 0.004 kg/m^3.

According to Eq. (2.4), when h = 1 m, we know

$$\Delta P = 9.8 \times 1 \times 0.004 = 0.039\,\text{Pa}$$

Since the thermal pressure is very small, illusion will be formed that the thermal prepared can be counteracted by the pressure difference easily. However, when door is closed, the intake flow rate by negative pressure difference is exerted on the small area such as door gap. When door is open, the convective flow rate by thermal pressure is exerted on a half of the door opening. When the value of pressure difference is equal to that of the thermal pressure, the former flow rate is much less than the latter. When the former flow rate was exerted on the door opening area, the air velocity formed cannot counteract the air velocity by the latter flow rate. The air velocity on door opening can be expressed as Eq. (3.2) in Chap. 3.

Because the area of the door opening is very large, which is different from the gap, the intake and outtake flow rates (Q_4 and Q_5) can be calculated with Eq. (2.5). The maximum of the parameter φ can be within 0.9 and 0.97, which is different from Sect. 3.1.

$$Q_4 = Q_5 = \varepsilon\varphi F_1\sqrt{\frac{2\Delta P}{\rho_1}} = \varepsilon\varphi F_2\sqrt{\frac{2\Delta P}{\rho_2}}\,(\text{m}^3/\text{s}) \quad (2.5)$$

where F_1 is the area of the outtake flow on the door opening; F_2 is the area of the intake flow on the door opening.

Because the density difference $\Delta\rho$ is very small, it can be simplified for calculation. It is supposed that $\rho_1 = \rho_2$ and $F_1 = F_2$. Equation (2.5) is different from Eq. (2.1) which is used for calculation of the leakage flow rate through door gap. In Eq. (2.1), $\mu = \varepsilon\varphi$, and ε is the contraction coefficient of the flow. But for door opening, $\varepsilon \approx 1$.

2.2.6 Relationship Between Temperature Difference and Pollutant Exchange Rate

According to Eq. (2.4), when the height of the door is 2 m, h = 1 m. The average air velocity and flow rate under different temperature differences are shown in Table 2.11. During the calculation process, Δt = 1 °C, $\Delta\rho$ = 0.004 kg/m^3, the width of door is set 0.9 m, h = 1 m and φ = 0.94.

It is shown from Table 2.11 that the flow rate of convective flow on door opening by 0.1 °C temperature difference reaches 0.07 m^3/s. It is equivalent to the

Table 2.11 Air velocity and flow rate of convective flow

Δt, °C	0.1	0.2	0.3	0.5	1	1.2	1.5	2.	2.5	3	3.5	4	4.5	5
V, m/s	0.076	0.107	0.13	0.17	0.24	0.26	0.29	0.34	0.38	0.42	0.45	0.48	0.51	0.54
Q_4 (Q_5), m^3/s	0.07	0.10	0.12	0.15	0.22	0.24	0.26	0.31	0.34	0.37	0.40	0.43	0.46	0.48

intake flow rate 0.072 m^3/s by negative pressure difference $\Delta P = -15$ Pa as shown in Table 3.1. Therefore, the influence of convective flow by temperature difference cannot be neglected. It is indeed difficult to counteract the influence of temperature difference only by pressure difference when door is open. This is consistent with the aforementioned measured flow direction on door opening.

After door is open, the pollutant exchange rate induced by door opening, movement of occupant and temperature difference is proportional to the flow rate of intake and outtake flow.

The exchange rate of flow by temperature difference is given by Table 2.11.

From previous section, for the area of 1.5 m^2 by door opening (usually the door will not be opened to the vertical position), the maximum flow rate induced by door opening within 2 s is $Q = 0.9$ m^3.

The flow rate induced by movement of occupant within 2 s is $Q = 0.28$ m^3. Therefore, the flow rate without temperature difference is:

$$\sum Q = 1.18\,\text{m}^3$$

The exchange of flow rate within 2 s when there is temperature difference is shown in Table 2.12.

According to the flow rate in Table 2.12, the relationship between the pollutant exchange rates with/without temperature difference can be obtained, which is shown in Fig. 2.27. It is shown that when the temperature difference is larger than 2 °C, the pollutant exchange rate will be greater by 50% from that without temperature difference.

It is shown from Fig. 2.27 that in theory the pollutant exchange rate for $\Delta t = 3$ °C increases by 39% than that for $\Delta t = 0.2$ °C. The pollutant exchange rate for $\Delta t = 5$ °C increases by 55% than that for $\Delta t = 0.2$ °C. But experiment shows that the maximum pollutant concentration (subtracted from the background concentration) for $\Delta t = 5$ °C is 2566.4 pc/L. The maximum pollutant concentration (subtracted from the background concentration) for $\Delta t = 3$ °C is 1622.9 pc/L. The maximum pollutant concentration (subtracted from the background concentration) for $\Delta t = 0.2$ °C is 1378.2 pc/L. Therefore in experiment the pollutant exchange rate for $\Delta t = 3$ °C increases by 18% than that for $\Delta t = 0.2$ °C. The pollutant exchange rate for $\Delta t = 5$ °C increases by 86% than that for $\Delta t = 0.2$ °C [7].

Based on the comparison between experimental data and theoretical data, the difference varies for different temperature differences. However, with the increase of temperature difference, the increasing trend of the pollutant leakage rate is consistent. For example, when the door of the ward opened firstly and then closed, the ratio of average concentration in the buffer room to that in the ward during the first 2 min is shown in Fig. 2.28, which is about 3.5–6.6%.

The relationship between the concentration increase by temperature difference and the time is shown in Fig. 2.29.

Table 2.12 Exchange of flow rate within 2 s with temperature difference

Δt, °C	0	0.1	0.2	0.3	0.5	1	1.2	1.5	2	2.5	3	4	4.5	5
Q, m^3/s	1.18	1.32	1.38	1.42	1.48	1.62	1.66	1.70	1.8	1.86	1.92	2.04	2.1	2.14

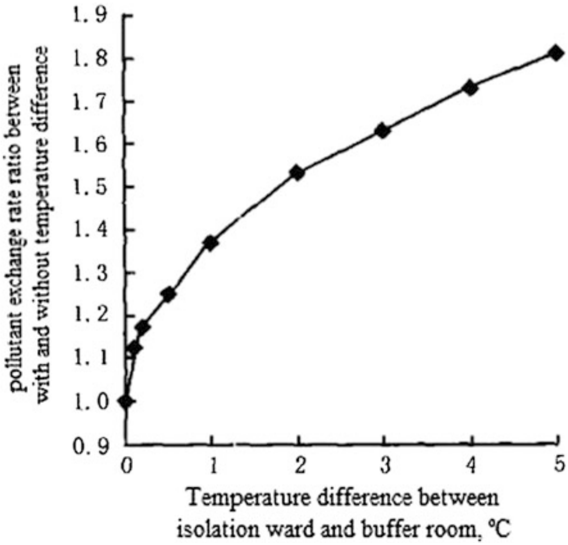


Fig. 2.27 Pollutant leakage rate by convective flow with temperature difference before and after door opening

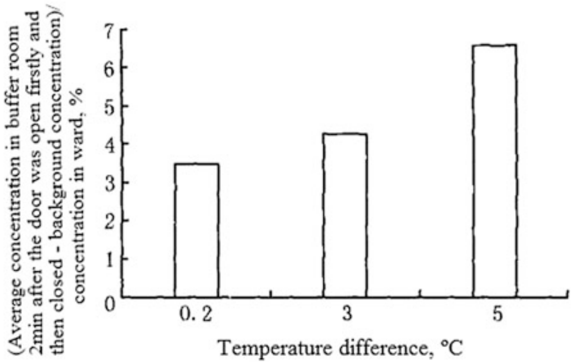


Fig. 2.28 Average concentration in buffer room 2 min after the door was open firstly and then closed

The phenomenon of aforementioned convective flow by temperature difference and its effect on pollutant exchange rate on door opening are rare in foreign standards and literatures. In "*Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Facilities*" issued by the Centers for Disease Control and Prevention (CDC) in U.S.A. in 1994, it was only mentioned that "indoor air distribution is affected by the temperature difference of air", but the influence of the temperature difference on the pollutant exchange was not noticed. In ASHRAE manual, this has been paid attention to. But it was only mentioned that when the door was open, "because convection occurs with temperature difference between two areas, air exchange by natural ventilation appears". There is no deep

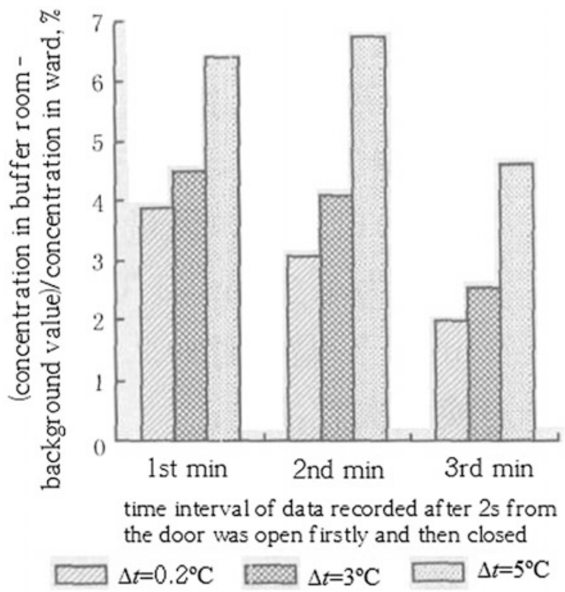


Fig. 2.29 Variation of concentration in buffer room 3 min after the door was open firstly and then closed

and quantitative analysis. The observatory results by foreign scholars have also been provided, which are shown in Figs. 2.30 and 2.31. But there is no further investigation.

In Fig. 2.30, the temperatures in the ward and in the corridor were 21 and 22 °C, respectively. Although air flow kept balanced at 1 m above the floor near the door opening, this is obviously the situation when door is open. But the velocity of air flow near the floor induced by temperature difference is near 0.3 m/s (equivalent to

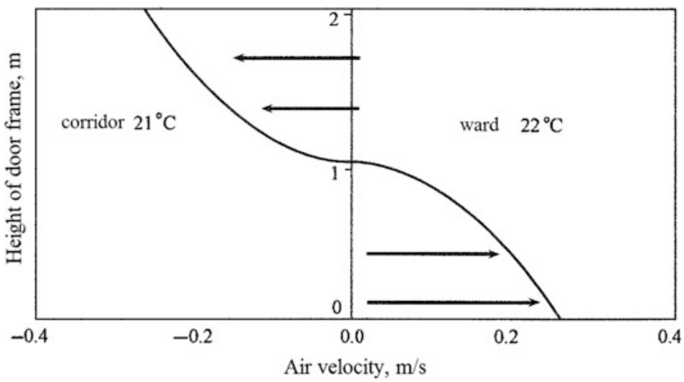


Fig. 2.30 Convection on door opening when $\Delta t = 1$ °C

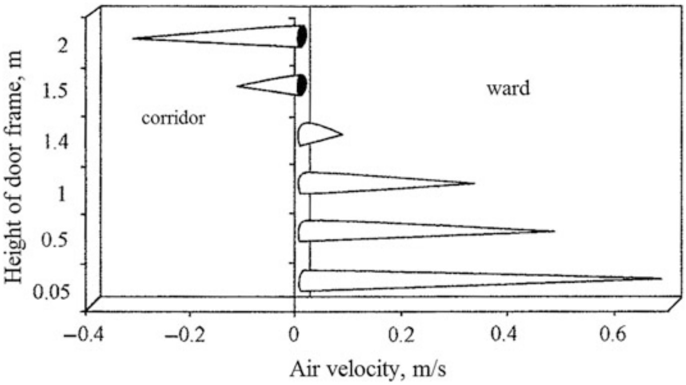


Fig. 2.31 Convection on door opening when Δt = 3.6 °C

600 m^3/h), which is in the opposite direction of the air flow in the upper region of door opening. Someone believed that when the air change rate could not reach 10 h^{-1} or 1200 m^3/h (when the original 600 m^3/h of the outtake flow in the upper region of door opening, or that of the intake flow in the lower region of door opening, needs to be counteracted, there should be the corresponding intake flow with flow rate 600 m^3/h in the lower region, or the corresponding outtake flow with flow rate 600 m^3/h in the upper region, respectively. Therefore it is 1200 m^3/h), pollutant will escape to the corridor. But this researcher did not pay attention to the impossibility for the formation of such a large exhaust flow in the ward. Even in the normal condition, the pressure difference is unable to counteract the convection by temperature difference. This conclusion has not been proposed. On the contrary, until now it is believed that the pressure difference is able to counteract the convection by temperature difference (refer to the section about pressure difference).

Figure 2.31 shows the flow direction on the cross section of the door with width 900 mm, when the temperature difference between two rooms reached 3.6 °C. It is shown that the air change rate at the height 1.45 m above the floor was almost 0, where can be considered to be the neutral plane. The air velocity in the lower region of the door opening from the corridor to the ward reached 0.7 m/s. The air velocity in the upper region of the door opening reached 0.3 m/s with the opposite direction. It was also pointed out that with the increase of exhaust air from the ward, the height of the neutral plane would move upwards.

Based on the above-mentioned description, experiment and calculation on several phenomena of door, no matter how airproof it is for the door of the isolation ward, the intake and outtake of air flow under dynamic condition cannot be prevented. Therefore, the airproof door cannot play the role of effective isolation.

Therefore, it is again a misunderstanding that airproof door must be installed for negative pressure isolation ward (In extreme case, the door interlock is used, or even the airproof door used in submarine is applied).

2.3 About Full Fresh Air

2.3.1 Outline

After SARS epidemic, the design personnel are inclined to adopt the full fresh air scheme during the design of the negative pressure isolation ward. It is believed that the circulation air cannot prevent the air pollution.

But when the related regulations abroad are referred, except the ASHRAE manual "*Health Care Facilities*" issued in 1991 and the Russian standard, full fresh air scheme is not necessary in other guidelines and the above-mentioned literatures revised after 2003, which is shown in Table 2.13. In the ASHRAE manual, apparatus with circulation air is not allowed. In the Russian standard, all the air should be exhausted outdoors.

In the guidelines issued by CDC in U.S.A., there are two situations when full fresh air system is not necessary and circulation air is permitted:

(1) Multi-room system. When air from these rooms should be recirculated to the HVAC system, HEPA filters should be installed at the individual exhaust (or return) air pipelines, instead of the total exhaust pipeline.
(2) Single room. When three kinds of installation types for HEPA filter are allowed: (a) HEPA filter is installed at the return air pipeline of the room, so that return air is filtered and then delivered into the room; (b) when HEPA filter is installed on wall or above the ceiling, indoor self-circulation air system is formed, so that the filtered air can be used again; (c) HEPA filter is installed in the filtration unit, but it is not specified by CDC that this kind of the filtration unit should be installed above the ceiling or in the room.

2.3.2 HEPA Filter and Virus Particles

The main concern about the scheme to use full fresh air only and no circulation air in negative pressure isolation ward is that there may be pathogenic microbes with enough concentration in recirculation air. Since the size of virus is very small, it is believed that they cannot be removed by HEPA filter. It is also considered that there are basically no pathogenic bacteria in fresh air.

The belief that virus cannot be removed by HEPA filter means that the virus size is too small. Indeed, the size of virus itself is too small, which is about 0.01–0.1 μm. But actually the virus is attached to its nutritious matters. They are released into the air by various forces such as coughing. This means that there are carriers for the existing virus (also including bacteria) in air. The diameter of these microbes with carriers was termed as the equivalent diameter [11]. For example, the size of the bacteriophage in the processing of the monosodium glutamate factory is about 2–5 μm. Selleris and Herniman investigated the foot-and-mouth disease virus (FMDV) in the natural world. Although the size itself is only 25–30 nm, after

Table 2.13 Related standards on flow rates of dilution air and fresh air

Standard	Specified flow rate for dilution air and fresh air
"*Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Facilities*" issued by CDC in U.S.A., ASHRAE 170 "*Ventilation of Health Care Facilities*"	In new-built or renovated isolation ward for prevention of airborne transmission, the air change rate >12 h^{-1} and the fresh air volume >2 h^{-1}
ASHRAE manual (2003) "*Health Care Facilities*" [14]	In isolation ward, the flow rate of dilution air >6 h^{-1} (based on requirement for odor and thermal comfort)
UK "*Guidance on the prevention and control of transmission of multiple drug-resistant Tuberculosis*" [14]	In new-built or renovated isolation ward for prevention of airborne transmission, the flow rate of dilution air $\geq 12\ h^{-1}$ and the fresh air volume $\geq 2\ h^{-1}$
CDC in U.S.A. "*Guidelines for environmental infection control in health care facilities*" [14]	In newly-built ward, the air supply volume $\geq 12\ h^{-1}$. In existing ward, the air supply volume $\geq 6\ h^{-1}$
AIA in U.S.A. "*Guidelines for design and construction of hospital and health care facilities*" [14]	In isolation ward for prevention of airborne transmission, consulting rooms for emergency or radiotherapy, the flow rate of dilution air $\geq 12\ h^{-1}$ and the fresh air volume $\geq 2\ h^{-1}$
DHHS in U.S.A. "*Guidelines for construction and equipment of hospital and medical facilities*" [14]	In isolation ward for prevention of airborne transmission, the air supply volume $\geq 12\ h^{-1}$ and the fresh air volume $\geq 2\ h^{-1}$. In the bathroom, laundry, waste disposal room, disinfection room, anteroom of isolation ward, the exhaust air volume $\geq 10\ h^{-1}$
Australia "*Guidelines for the classification and design of isolation rooms in health care facilities*" [14]	In negative pressure isolation ward, the flow rate of dilution air should be the larger value between 12 h^{-1} and 522 m^3/h
USA "*Guidelines on the design and operation of HVAC systems in disease isolation areas*" [14]	In newly-built isolation ward, disposal room and mortuary, the flow rate of dilution air $\geq 12\ h^{-1}$. In the bathroom, the exhaust air volume $\geq 10\ h^{-1}$. In the consulting room for infectious patient, the flow rate of dilution air $\geq 15\ h^{-1}$ and the fresh air volume $\geq 2\ h^{-1}$
"*Guideline for Design and Operation of Hospital HVAC Systems*" (HEAS-02-2004) established by Healthcare Engineering Association of Japan	In isolation ward, the total air supply volume should be 12 h^{-1}, and the fresh air volume $\geq 2\ h^{-1}$
DIN 1946-4 standard "*Ventilation and air conditioning - Part 4: Ventilation in buildings and rooms of health care*" by Deutsches Institut Fur Normung E.V.	In isolation ward, reception room and ICU, the fresh air rate per person is 40 m^3/h. In the ward containing isolated patients with infectious potential, the fresh air rate per person >100 m^3/h (it is known that it should be the circulation air)
Russian standard GOST R 52539-2006 "A*ir cleanliness in hospitals. general requirements*"	In infectious isolation ward (where local air cleaning equipment can be installed), the air change rate should be 12–20 h^{-1}, and total air is exhausted outdoors

Table 2.14 Comparison of penetration for filters

Filter	Flow rate, m^3/h	Pressure difference, Pa	Penetration, %			
			Bacteriophage, 0.1 μm	Virus, 0.3 μm	FMDV, 0.01–0.012 μm	DOP, 0.3 μm
HEPA A	42.5	264	0.0039			0.011
HEPA B	42.5	175	0.00085			0.02
HEPA C	42.5	135	0.00085			0.006
HEPA D	–	–	0.003	0.0036	0.001	0.01

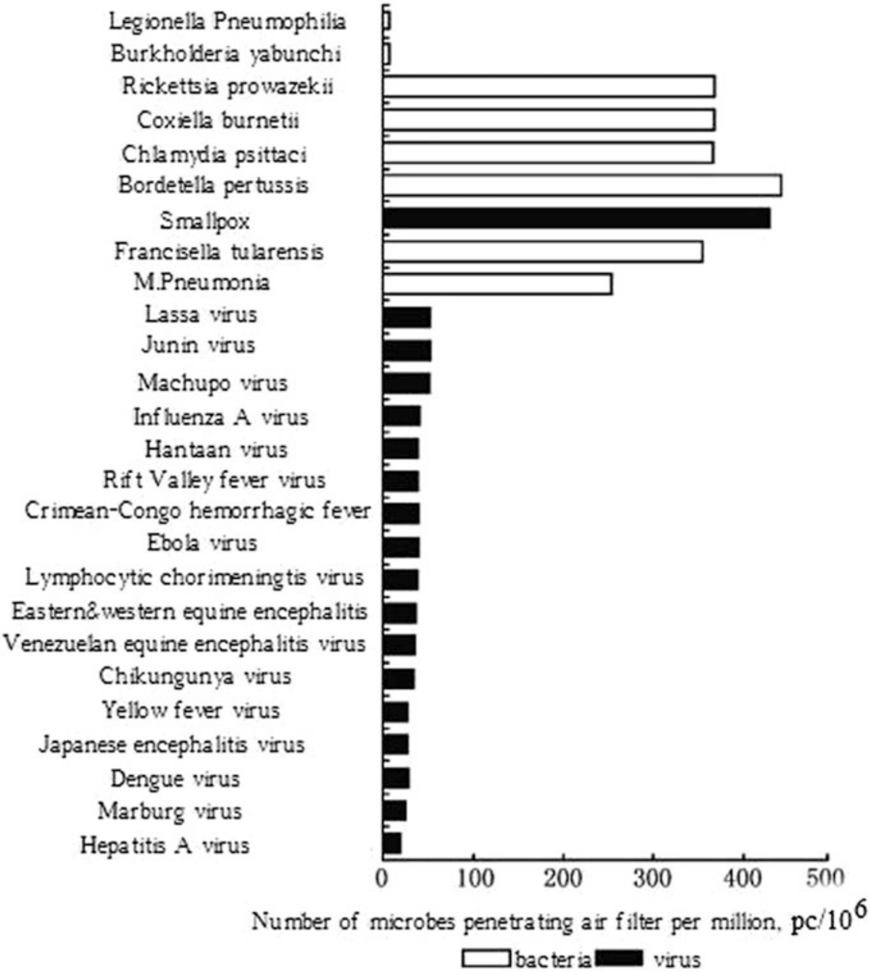


Fig. 2.32 Penetration of microbes through air filters

sampled with cascade liquid impactor, 65–71% of the airborne particles containing virus have sizes larger than 6 μm, and 19–21% have sized between 3 and 6 μm, and only 10–11% have sizes smaller than 3 μm. Therefore, is the number of particles containing virus with size 0.01–0.1 μm (or the virus particles with size 0.01–0.1 μm) too less [12]?

Experiment has shown that the efficiency of HEPA filter for 0.1 μm particles is much larger than that for 0.3 μm, which is shown in Table 2.14 [10]. This also means that the equivalent diameter of virus is much larger than 0.3 μm.

Based on the above-mentioned introduction, it does not mean that the filtration efficiency for bacteria is large, while that for virus is small. Figure 2.11 shows that the filtration efficiency for may virus is much larger than that for bacteria [13] (Fig. 2.32).

In total, the belief to use full fresh air only and no circulation air in negative pressure isolation ward is the third misunderstanding.

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