Preplanned Studies

Aerosol Transmission of SARS-CoV-2 in Two Dormitories — Hubei and Shandong Provinces, China, 2020

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Summary

What is already known about this topic?

Aerosol transmission is one route for the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). However, uncertainty remains on the threshold of ventilation rate in its occurrence.

What is added by this report?

Based on two cases in Shandong Province and Hubei Province, the effect of wearing masks and the minimum ventilation required to reduce coronavirus disease 2019 (COVID-19) aerosol transmission was determined.

What are the implications for public health practice?

No masking and low ventilation rates lead to a relatively high contribution of aerosols to COVID-19 transmission. Thus, public awareness of wearing masks should increase and the ventilation rate should be sufficiently higher than the minimum required ventilation.

Aerosol transmission of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has been confirmed in many studies (*1–3*). Previous studies have shown that the highest concentration of outbreak cases outside of the Hubei Province came from indoor environments (*4*), especially ones with overcrowding and poor ventilation. A previous theoretical model predicted that a ventilation rate above 36 m^3/h per person can effectively reduce the risk of aerosol infection when people socially distance (*5*); however, this has not been confirmed by real-world data.

Overall, 2 COVID-19 outbreaks in the dormitory buildings in Hubei and Shandong Province — with different mask wearing habits and rates of indoor ventilation — were analyzed in February 2020. From June 5–13, 2020, an onsite investigation was conducted. The epidemiological data were collected and ventilation conditions were investigated at the time of occurrence. Preliminary information of the cases was obtained, including dates of symptom onset, mask wearing habits, and detailed infection data, such as the number of infected persons in each room and their distributions. The information collected also includes the building information, the opening of doors and windows, and the mechanical ventilation conditions.

Experiments were carried out according to whether doors or windows were open and ventilation equipment was on during the epidemic. The ventilation rate was measured by CO_2 tracer-concentration decay method. More than two concentration detectors and temperature recorders were arranged in each room. After releasing a certain concentration of CO_2, the change in indoor CO_2 concentration was continuously recorded for 2 hours with a sampling interval of 1 minute. A total of 54,848 experimental data points were obtained, including indoor CO_2 concentration, outdoor CO_2 concentration, indoor and outdoor temperature, etc.

For the dormitory building in Shandong Province, the main ventilation mode was mechanical ventilation. When the wind pressure and the window opening were both small, the difference in ventilation rate between winter and summer was not obvious. For the building in Hubei Province, there was no mechanical ventilation and it was located in the city center, densely surrounded by buildings; therefore, the wind ventilation was ignored and only buoyancy ventilation was considered. The natural ventilation rate was calculated by the following formula (*6*):

$$Q = \frac{1}{3} C_D A \sqrt{gH \frac{T_i - T_0}{T_i}}$$

$$\textit{Let } k = \frac{1}{3} C_D A \sqrt{gH}$$

$$Q = k\sqrt{\frac{T_i - T_0}{T_i}}$$

where Q is the natural ventilation rate (m^3/h); C_D is the flow coefficient; A is the window opening area (m^2); g is the gravitational acceleration; H is the height of the window (m); T_i is the indoor temperature (K); and T_0 is the outdoor temperature (K).

Through this field experiment, the room ventilation rate and the difference between indoor and outdoor temperature were measured, and the k value of each room was calculated. Outdoor temperatures during the disease outbreak period were obtained through a meteorological website and the average outdoor nighttime temperature was used for calculations.

According to our investigation, the transmission period for the Shandong Province was mainly from January 21 to February 12, 2020, and the infected people were concentrated in the north dormitory building.

The first case of infection was a dormitory supervisor who had been infected before January 21, due to contact with an asymptomatic infected person. There were 30 dormitory rooms in the building with an average number of 9 residents in each room. During the epidemic, internal personnel did not wear masks and they were in frequent contact. In this case, the infection rate in 30 rooms was between 29%–100%, of which 7 rooms had a 100% rate of infection. During the outbreak, the interior doors of the building were open, and the exterior windows were closed. The ventilation of rooms mainly depended on negative pressure generated by the four exhaust fans in the bathroom that were always on.

This case also occurred in Hubei Province due to infections of dormitory staff. The epidemic spread mainly from January 21 to February 11. There were 90 rooms in the building, and the average number of residents in each room was 21. Internal personnel used hand-stitched coarse cloth masks throughout the day. There was no mandatory mask wearing requirement at night; however, they were required to sleep on time. According to interviews conducted, a centralized area consisting of ten rooms (recorded as area M) had residents who were older and weak. During winter, they kept doors and windows closed all day to prevent catching a cold. Members in this area had a high awareness of self-protection and wore masks all day. Most of the residents in other areas (recorded as zone N) were young and middle-aged. They did not have a habit of wearing masks at night, and they opened windows or doors all day to enhance ventilation. The overall rate of infection was between 0% and 56%, of which 14 rooms had a 0% rate of infection.

According to the simulation results, the ventilation rate of each room in Shandong Province was 129–246 m^3/h. The range of ventilation rate per person was 12.9–32.4 m^3/h. The ventilation rate of each room in Hubei Province was between 169 and 1,790 m^3/h (Supplementary Table S1). The ventilation rate per person was between 6.9 and 56.4 m^3/h (Figure 1).

The average room ventilation in Hubei M Zone was 236 m^3/h and the average ventilation rate per person was 7.7 m^3/h. The average room ventilation in Hubei N Zone was 601 m^3/h and the average ventilation rate per person was 28 m^3/h. The room ventilation and ventilation rate per person in Zone M were significantly lower than those in Zone N. However, the average infection rate was 8% in Zone M and 16% in Zone N. Zone M achieved a lower infection rate with worse ventilation levels, reflecting how mask wearing habits reduce infection rates.

In comparing the Shandong case with zone N of the Hubei case, their ventilation rates were both between 12.9 and 32.4 m^3/h per person (Figure 2); however, the average infection rate for Zone N was 18% and 74% for the Shandong case. The difference in the likelihood of infection between the two regions also reflected the significant effect of mask wearing habits.

The data from the Zone N in Hubei case showed that there was an obvious threshold of ventilation rate (Figures 1 and 2). When the room ventilation rate was higher than 800 m^3/h or 40 m^3/h per person, the rate of infection was less than 25%. Therefore, it was concluded that the contribution of aerosol transmission was very low. When the room ventilation rate was lower than 800 m^3/h or 40 m^3/h per person, the highest infection rate reached 56%, indicating a high risk of aerosol transmission.

DISCUSSION

Previous studies have shown that SARS-CoV-2 can survive 3 hours in aerosols (*7*), and a number of cases have proven the possibility of aerosol transmission of COVID-19, especially in poorly ventilated and crowded spaces. Li Yuguo et al. discussed the possibility of aerosol transmission due to the poor ventilation below 3.2 L/s (11.5 m^3/h) per person through the analysis of the actual case. However, they did not determine the minimum ventilation requirement for mitigating airborne transmission of COVID-19 (*8*–*9*). By analyzing the ventilation rate and infection rate of the dormitories in Hubei and Shandong Province, the change of infection rate was obtained within a larger range of ventilation rates. Our

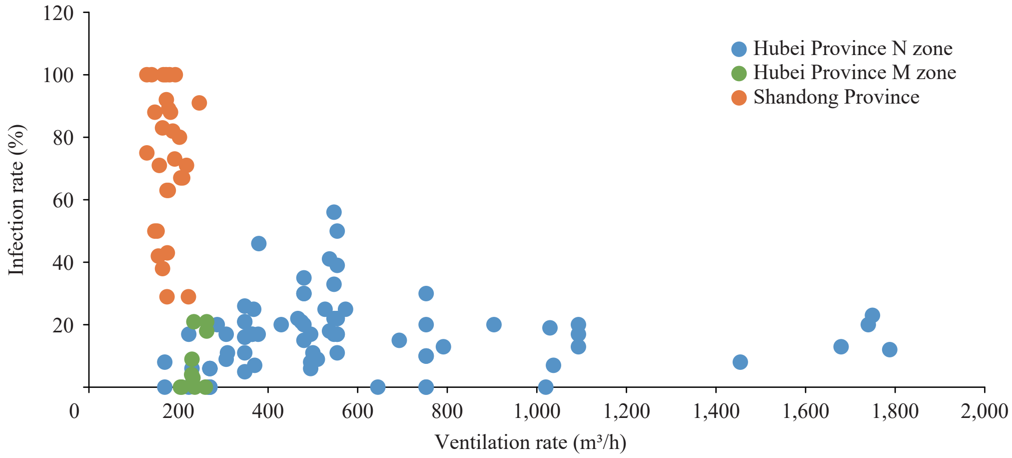

FIGURE 1. Relationship between room infection rate and room ventilation rate in two dormitory buildings in Hubei and Shandong Province.
Note: Each point in the figure represents a room, the abscissa axis represents the ventilation rate (m^3/h), and the ordinate axis represents the infection rate (%).

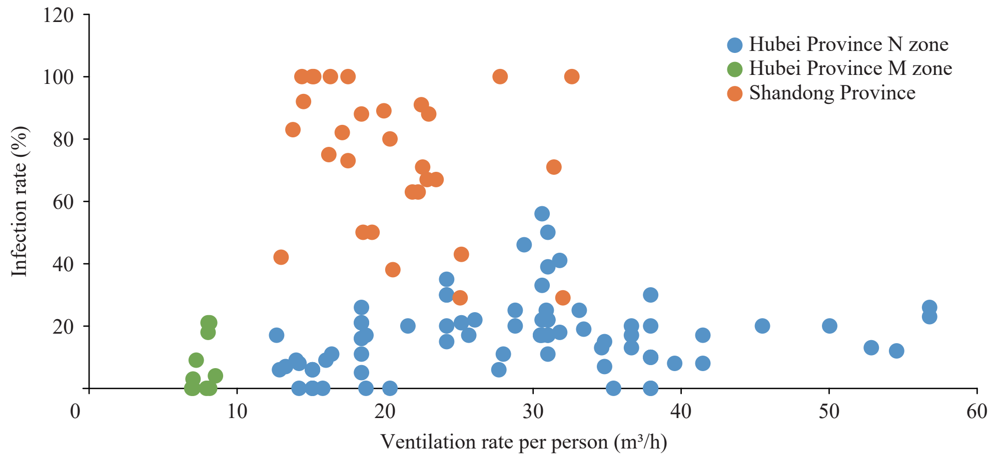

FIGURE 2. Relationship between room infection rate and room ventilation rate per person in two dormitory buildings in Hubei and Shandong Province.
Note: Each point in the figure represents a room, the abscissa axis represents the ventilation rate per person (m^3/h), and the ordinate axis represents the infection rate (%).

results showed that if the ventilation rate per person was higher than 40 m^3/h, the risk of aerosol transmission could be greatly reduced.

Through analyzing the actual data of two dormitory buildings with different mask wearing habits, it was found that even wearing hand-stitched coarse cloth masks can significantly reduce the risk of infection.

This study has some limitations. When analyzing the relationship between infection rate and ventilation rate, the statistics and comparison were carried out in the unit of room, and the difference of dormitory members in different bed positions were not discussed. Also, the indoor personnel's behavior could only rely on recollections from memory.

These results help guide COVID-19 prevention and control in dormitory spaces, suggesting that people should wear masks when entering or staying in a confined space and a sufficient ventilation rate above 40 m^3/h per person should be maintained.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. The location, ventilation rate, ventilation rate per person and infection rate of each room in two dormitories.

Zone	Room No.	Floor	Room ventilation (m^3/h)	Ventilation rate per person (m^3/h)	infection rate (%)
Hubei Province N zone	1	1	270	15	0
Hubei Province N zone	2	1	266	15.7	0
Hubei Province N zone	3	1	270	15	6
Hubei Province N zone	4	1	270	15	0
Hubei Province N zone	5	1	270	15	6
Hubei Province N zone	6	1	270	15	0
Hubei Province N zone	7	1	270	15	6
Hubei Province N zone	8	1	230	12.8	6
Hubei Province N zone	9	1	169	14.1	0
Hubei Province N zone	10	1	169	14.1	8
Hubei Province N zone	11	1	510	15.9	9
Hubei Province N zone	12	2	537	31.6	41
Hubei Province N zone	13	2	527	32.9	25
Hubei Province N zone	14	2	537	31.6	18
Hubei Province N zone	15	2	547	30.4	22
Hubei Province N zone	16	2	547	30.4	33
Hubei Province N zone	17	2	547	30.4	17
Hubei Province N zone	18	2	547	30.4	56
Hubei Province N zone	19	2	495	27.5	6
Hubei Province N zone	20	2	364	30.3	17
Hubei Province N zone	21	2	364	30.3	17
Hubei Province N zone	22	2	1,029	33.2	19
Hubei Province N zone	23	3	554	30.8	17
Hubei Province N zone	24	3	554	30.8	22
Hubei Province N zone	25	3	554	30.8	11
Hubei Province N zone	26	3	554	30.8	39
Hubei Province N zone	27	3	554	30.8	22
Hubei Province N zone	28	3	554	30.8	50
Hubei Province N zone	29	3	554	30.8	17
Hubei Province N zone	30	3	500	27.8	11
Hubei Province N zone	31	3	368	30.7	25
Hubei Province N zone	32	3	379	29.2	46
Hubei Province N zone	33	3	573	28.6	25
Hubei Province N zone	34	3	904	45.2	20
Hubei Province N zone	35	4	480	24	35
Hubei Province N zone	36	4	480	24	15
Hubei Province N zone	37	4	480	24	20
Hubei Province N zone	38	4	466	25.9	22
Hubei Province N zone	39	4	474	25	21
Hubei Province N zone	40	4	480	24	30

Continued

Zone	Room No.	Floor	Room ventilation (m^3/h)	Ventilation rate per person (m^3/h)	infection rate (%)
Hubei Province N zone	41	4	480	24	30
Hubei Province N zone	42	4	429	21.4	20
Hubei Province N zone	43	4	306	25.5	17
Hubei Province N zone	44	4	286	28.6	20
Hubei Province N zone	45	4	791	34.4	13
Hubei Province N zone	46	5	753	37.7	20
Hubei Province N zone	47	5	753	37.7	30
Hubei Province N zone	48	5	753	37.7	10
Hubei Province N zone	49	5	753	37.7	0
Hubei Province N zone	50	5	753	37.7	10
Hubei Province N zone	51	5	753	37.7	0
Hubei Province N zone	52	5	753	37.7	10
Hubei Province N zone	53	5	693	34.6	15
Hubei Province N zone	54	5	495	41.2	17
Hubei Province N zone	55	5	495	41.2	8
Hubei Province N zone	56	5	1,454	39.3	8
Hubei Province N zone	57	6	348	18.3	26
Hubei Province N zone	58	6	348	18.3	21
Hubei Province N zone	59	6	348	18.3	16
Hubei Province N zone	60	6	348	18.3	16
Hubei Province N zone	61	6	348	18.3	5
Hubei Province N zone	62	6	348	18.3	21
Hubei Province N zone	63	6	348	18.3	11
Hubei Province N zone	64	6	309	16.3	11
Hubei Province N zone	65	6	223	18.6	17
Hubei Province N zone	66	6	223	18.6	0
Hubei Province N zone	67	6	645	20.2	0
Hubei Province N zone	68	2	1,679	52.5	13
Hubei Province N zone	69	2	1,749	56.4	23
Hubei Province N zone	70	2	1,788	54.2	12
Hubei Province N zone	71	2	1,749	56.4	26
Hubei Province N zone	72	2	1,740	49.7	20
Hubei Province N zone	73	3	1,020	35.2	0
Hubei Province N zone	74	3	1,093	36.4	17
Hubei Province N zone	75	3	1093	36.4	13
Hubei Province N zone	76	3	1,093	36.4	20
Hubei Province N zone	77	3	1,037	34.6	7
Hubei Province N zone	78	4	306	13.9	9
Hubei Province N zone	79	4	378	12.6	17
Hubei Province N zone	80	4	370	13.2	7
Hubei Province M zone	1	2	207	6.9	0
Hubei Province M zone	2	2	234	8.1	21

Continued

Zone	Room No.	Floor	Room ventilation (m^3/h)	Ventilation rate per person (m^3/h)	infection rate (%)
Hubei Province M zone	3	2	229	8.5	4
Hubei Province M zone	4	2	236	7.9	0
Hubei Province M zone	5	2	204	7	0
Hubei Province M zone	6	3	230	7.2	9
Hubei Province M zone	7	3	263	8	18
Hubei Province M zone	8	3	260	8.1	0
Hubei Province M zone	9	3	263	8	21
Hubei Province M zone	10	3	232	7	3
Shandong Province	1	2	152	19	50
Shandong Province	2	2	147	18.3	88
Shandong Province	3	2	129	16.1	75
Shandong Province	4	2	147	18.4	50
Shandong Province	5	2	129	16.2	100
Shandong Province	6	2	140	17.4	100
Shandong Province	7	2	157	22.4	71
Shandong Province	8	2	202	20.2	80
Shandong Province	9	2	172	14.3	100
Shandong Province	10	2	191	17.4	73
Shandong Province	11	3	227	32.4	100
Shandong Province	12	3	182	22.8	88
Shandong Province	13	3	178	19.8	89
Shandong Province	14	3	174	24.9	29
Shandong Province	15	3	177	22.1	63
Shandong Province	16	3	174	21.7	63
Shandong Province	17	3	173	14.4	92
Shandong Province	18	3	180	15	100
Shandong Province	19	3	187	17	82
Shandong Province	20	3	164	13.7	83
Shandong Province	21	4	218	31.2	71
Shandong Province	22	4	175	25	43
Shandong Province	23	4	222	31.8	29
Shandong Province	24	4	193	27.6	100
Shandong Province	25	4	246	22.3	91
Shandong Province	26	4	164	20.4	38
Shandong Province	27	4	166	15.1	100
Shandong Province	28	4	209	23.3	67
Shandong Province	29	4	205	22.7	67
Shandong Province	30	4	155	12.9	42