BEHAVIOR OF DROPLETS AND DROPLET NUCLEI FROM COUGHING SIMULATOR IN SICKROOM WITH DISPLACEMENT VENTILATION

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Abstract

Displacement ventilation has an excellent ventilation efficiency to remove contaminants such as odor emitted by excrement or patients in a sickroom of hospital. It is, however, indicated by Li et al. (2011) that there is a possibility that displacement ventilation causes the retention of droplet nuclei expired by coughing of patient at occupied zone in the room, and the infection risk is increased in comparison with mixing ventilation. It is, therefore, important to made clear the risk of infection in the room with displacement ventilation. In this paper, the particle concentration of droplet nuclei was measured in a full-scale mock-up of four-bed ward in order to examine the distribution of concentration of droplet nuclei with different sizes. A coughing machine developed by Ogata et al.(2018) was introduced to simulate the patient's coughing. The particle concentrations were measured under four coughing situations; a standing person coughing horizontally, a sitting person coughing horizontally, a lying person coughing horizontally and a lying patient coughing upward. In the experiment, supply air was filtered by HEPA filters. In order to estimate the possibility of infection due to the inhalation of droplet nuclei, the index of local cumulative dose (*LCD*) was introduced. As a result, it is turned out that *LCD* is much higher at the upper zone than the lower zone and the order of *LCD* is standing person coughing horizontally, sitting person coughing horizontally, lying person coughing horizontally, and lying person coughing upward.

Keywords: displacement ventilation, coughing machine, droplet nuclei

1 Introduction

Displacement ventilation is an excellent ventilation system with high efficiency of supplying fresh clean air to occupants and also exhausting contaminants from heat source such as human body. Introducing displacement ventilation into the sickroom is a good way to avoid odor of patients or excrement for the comfort of patients, workers and visitors. There is, nevertheless, infectious problem pointed out by Li et al. (2011). The problem is so-called airborne infection due to fine droplet nuclei containing bacillus or virus spread out in the room. The infectious diseases by droplet nuclei are said to be tuberculosis, measles and chickenpox. In the room with displacement ventilation, many droplet nuclei tend to float for a long time in the air because of stable temperature stratification and stagnant airflow. But this phenomenon should depend on the position and attitude of coughing person and the direction of coughing. In this study, the experiments using full scale chamber simulating four-bed ward with displacement ventilation were conducted to examine the distribution of concentration of droplet nuclei in the air.

2 Experimental setup

2.1 Full-scale experimental chamber and coughing machine

The outline of experimental chamber is shown in Figure 1. This chamber is originally an artificial climate chamber where temperature and humidity can be controlled optionally. The exhaust airflow rate is 394 m^3/h. Four beds with person simulators (40W for each) were installed in the chamber, four black lamps (light bulb with dark violet glass generating heat of 60W for each) are arranged inside as other heat sources in sickroom. Supply air is filtered by HEPA (high-efficiency particulate air filters) installed at the supply openings on the partition wall insulated by styrene foam. The particle concentration inside the room can be decreased to 500,000 [particles/m^3] (diameter ≥ 0.3μm) as a background concentration.

Coughing of person is simulated by a coughing machine invented by Ogata et al. (2018), and the solution of sodium chloride of 1% was used instead of water. Sprayed mists of solution are evaporated in the air and many particles of sodium chloride with various diameters are made. Real cough droplet nuclei are considered to be simulated by these particulates made from the coughing machine.

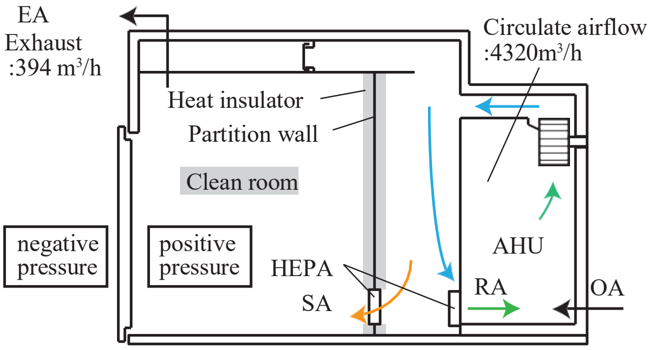

Figure 1. Outline of experimental chamber

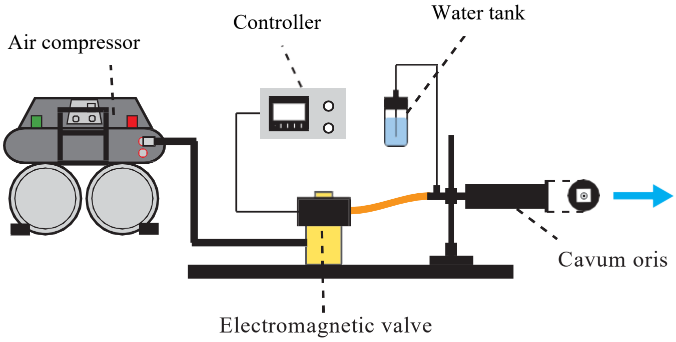

Figure 2. Outline of experimental chamber

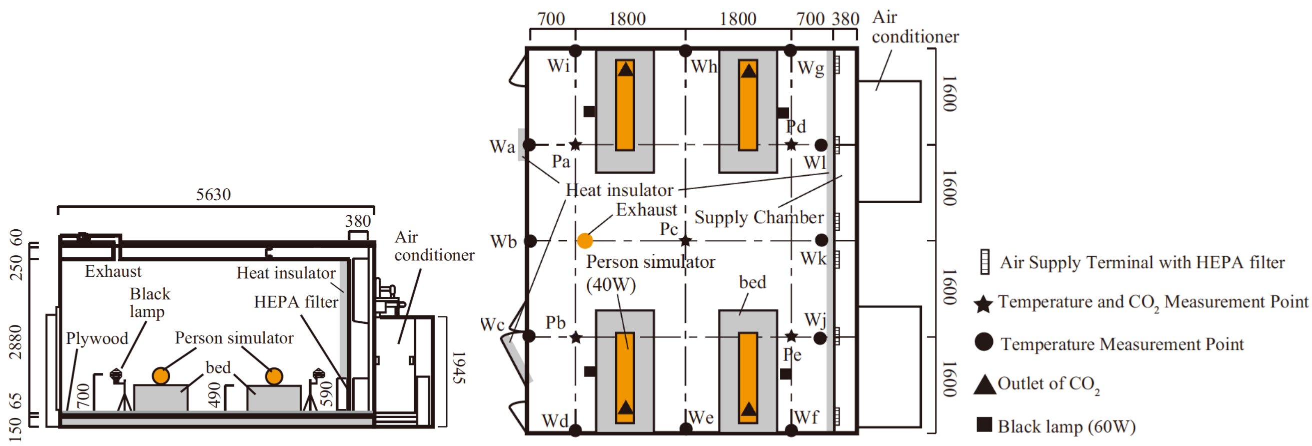

Figure 3. Section and plan of experimental chamber

2.2 Experimental conditions and measurement outline

By means of coughing machine, three times of coughing were made with the duration time of 0.3 seconds for each coughing and the interval time of 3 seconds. The particle concentration is measured by a particle counter with the diameter range of 0.3~5μm. CO_2 was emitted at each person simulator as a tracer gas of contaminant from patients on the beds. Temperature and CO_2 concentration were measured. Measurement points are indicated in Figure 3. As is shown in Figure 4, four cases of coughing condition were tested: (Case-1) a standing person coughing horizontally, (Case-2) a sitting person coughing horizontally, (Case-3) a lying person coughing horizontally and (Case-4) a lying patient coughing upward. The measurement points of particle concentration are shown in Figure 4.

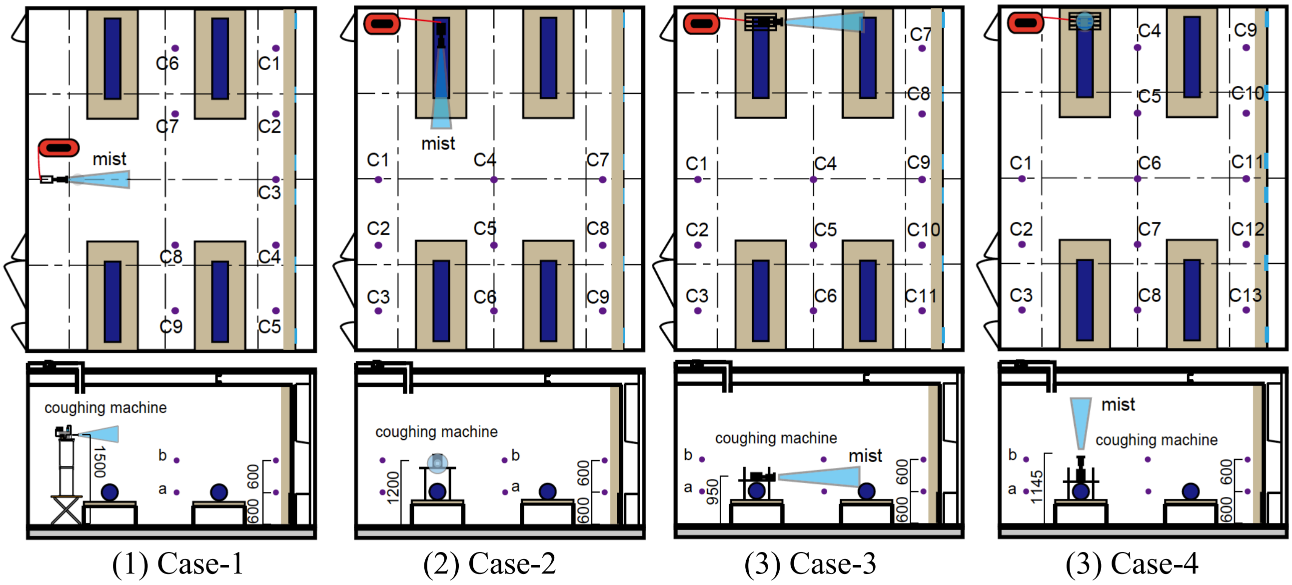

Figure 4. Measurement points of temperature and CO_2 concentration in each case

3 Results and discussion

3.1 Vertical distribution of temperature and CO_2 concentration

In Figure 5 and 6, the example of vertical distribution of temperature and CO_2 concentration are shown. In Figure 5, Wi, Wd, etc. is the surface temperature of walls and Pa, Pb, etc. are the air temperature. There can be seen slight temperature difference between wall temperature and air temperature, which causes some amount of downflow along walls conveying contaminant into the lower zone. There can be seen, however, contaminant interface inside the room in Figure 6.

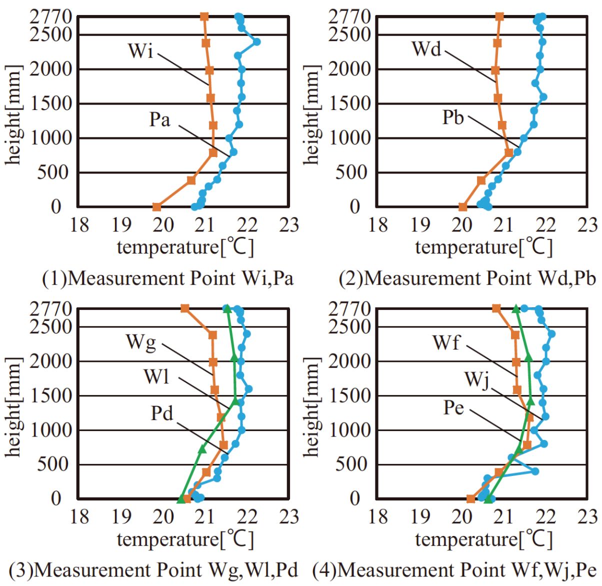

Figure 5. Vertical temperature distribution

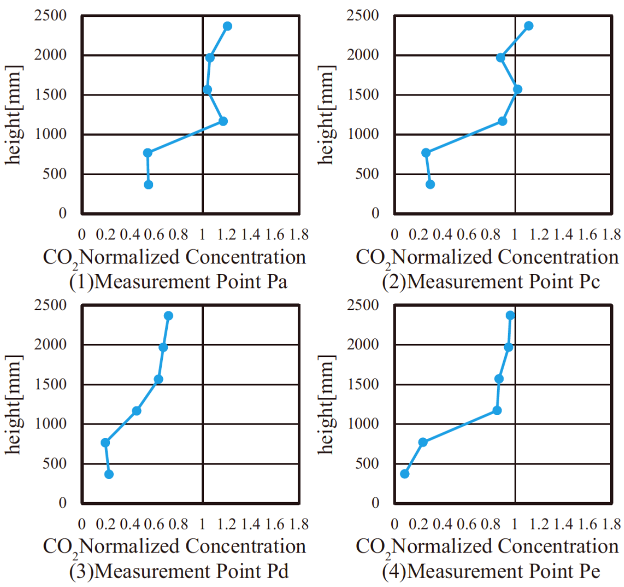

Figure 6. Vertical distribution of CO_2 concentration

3.2 Concentration of droplet nuclei made from coughing machine

An example of the variation of particle concentration in Case-1 is shown in Figure 7. It is shown that the particle concentration increases steeply after the coughing, and after the peak the concentration it decays exponentially. These curves show that the smaller the particle is, the decay need the more time. Here the local cumulative dose is defined as Eq. (1).

$$LCD = \int_0^{\infty} C_{p(t)} dt \qquad (1)$$

From Figure 8, *LCD* is the smallest in Case-4, and *LCD* in the upper zone is higher than the lower zone. The smaller droplet nuclei show the higher particle concentration.

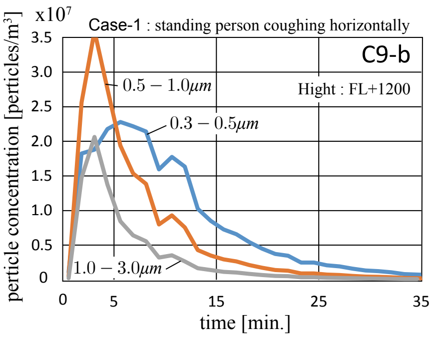

Figure 7. Variation of particle concentration at C9 (FL+1200) in Case-1

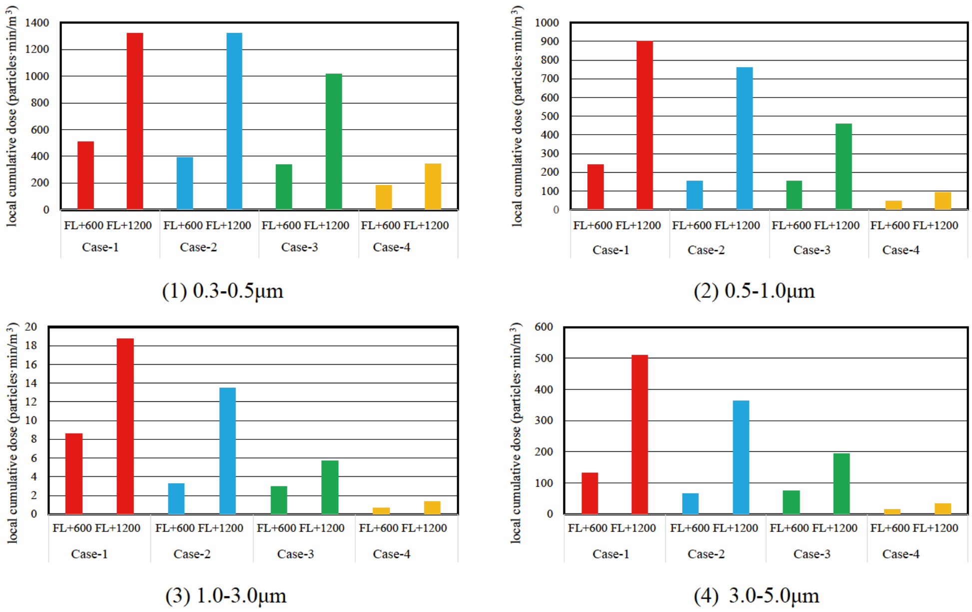

Figure 8. Comparison of LCD between the heights, the cases and the particle sizes.

More detailed results and discussion will be presented in the conference presentation.

4 Conclusion

The risk of infection due to cough droplet nuclei depends on the coughing directions. Patients should be prevented from coughing horizontally, if there are no curtains to isolate the patients.

5 Acknowledgements

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6 References

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