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STUDY ON MEASUREMENT TECHNIQUE OF MULTIZONE VENTILATION EFFECTIVENESS USING A SCALE MODEL

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ABSTRACT

In airtight houses, it is important to control the ventilation air flow of each room in order to ensure good indoor air quality, and the mechanical ventilation equipment should be designed carefully, considering the ventilation effectiveness in rooms. An experiment with a multizone scale model of three zones is carried out and the measurement techniques of ventilation effectiveness, that is, the step-up method and the step-down method, are applied to clarify the ventilation effectiveness in three rooms under various conditions of ventilation air flow volume and recirculated air flow rate. Firstly, the reproducibility of the experiment is examined and the results by the step-up method and the step-down method are compared. Then, the effect of ventilation air flow rate and recirculated air flow rate on ventilation effectiveness are clarified.

KEYWORDS Ventilation Effectiveness, Multizone, Scale Model, Measurement

INTRODUCTION

In airtight houses, one of the main issues is to promote energy conservation and maintain a comfortable indoor environment simultaneously. Concerning room air ventilation, the decrease of natural ventilation resulting from less air leakage may cause a problem with indoor air quality. Therefore such houses should be installed with mechanical ventilation equipment to control the ventilation air flow of each room. Also, the mechanical ventilation equipment should be designed carefully, considering the ventilation effectiveness in rooms. An experiment with a multizone scale model of three zones, 1/3 in length, is carried out. After the reproducibility for the measuring techniques of ventilation effectiveness, that is, the step-up method and the step-down method are examined, the effect of the ventilation air flow volume and the recirculated air flow rate on the ventilation effectiveness are clarified.

INSTRUMENTATION

A Scale Model

The scale model, which is made of acrylic boards for the ceiling and plywood boards for walls and floors, consists of three rooms and has the dimensions of 1.6 m in depth, 1.6 m in width and 0.8 m in height as shown in Fig.1. The inside surfaces except the ceiling are covered with a thin aluminum layer to avoid the absorption and desorption of CO_2 gas. An orifice plate is installed at each opening between room 1 and room 2 and between room 2 and 3. The relationship between the flow rate and the pressure difference across the orifice plate has been measured previously. A small fan is located between room 3 and room 1 to recirculate the air from room 3 to room 1. The fan for the whole ventilation is regulated with an inverter and the small fan for the recirculation is regulated with a voltage transformer.

Measuring Methods

The step-up method and the step-down method are applied for measuring the ventilation effectiveness. CO_2 is used as a tracer gas. The gas concentration is measured at 7 points as shown in Fig.1. Firstly, the air flow rate of each opening is controlled by the fans. After the CO_2 gas concentration becomes equal to the concentration of outside air, CO_2 gas is injected into the supply duct at a certain rate and the measurement is continued until the concentration at every measuring point is stable (Step-up method). Next, after stopping the CO_2 gas injection, the gas concentration at each point is measured until the concentration decreases to be equal to the concentration of outside air (Step-down method). The gas concentration is measured by an infrared analyzer by changing the connection with sampling tubes from the scale model.

Experimental Conditions

The experimental conditions are determined to clarify, (1)the reproducibility of the experiment (Exp.1), (2)the difference between the step-up method and the step-down method (Exp.2), (3)the effect of ventilation air flow rate on the ventilation effectiveness, (Exp.2'), and (4)the effect of the recirculation air flow rate on the ventilation effectiveness, (Exp.3). The experiments resulted in 19 tests under the conditions shown in Table 1.

Calculation of Ventilation Effectiveness

The local mean age ($\overline{\tau}_P$), the nominal time constant ($\overline{\tau}_n$), and the local air change index (ε_P) are calculated with the formulae shown in Table 2 (AIVC 1990).

RESULTS AND DISCUSSION

Reproducibility of Experiment (Exp.1)

Cases without recirculation air flow Measurements are carried out under the conditions that N_R is zero, i.e. the opening d is closed, and N_T is about 20[1/h]. The gas concentration in the exhaust duct is measured continuously in test 3 and every 5 minutes in the other tests. The concentration decays of the three tests by the step-down method are shown in Fig.2 and Table 3. The decay curves are almost the same, where N_T varies within a difference of 6% and ε_P varies within a difference of 3%.

Cases with recirculation flow When N_R is about 40[1/h] and N_T is about 20[1/h], the gas concentration in the exhaust duct is measured continuously in test 6 and every 5 minutes in the other tests. The concentrations of the six tests by the step-down method are shown in Fig.3 and Table 4. In the case of recirculation flow, it was difficult to control the ventilation air flow at a certain value. therefore N_T has a difference of 8% and the gas concentration scatters compared to the concentration in the case that N_R is zero. Consequently, ε_P has a difference of 24%, however, tests 1 and 2, tests 3 and 4, and tests 5 and 6, where the differences of N_T are within only 1% between all tests, have a difference of ε_P of 3%, 6% and 16%, re spectively.

Comparison of Step-Up method and Step-Down Method in Cases without Recirculation Air Flow (Exp. 2 and 2')

When N_R is 0 and N_T varies from 10[1/h] to 50 [1/h], the gas concentrations at the exhaust duct are measured continuously and are shown in Fig.4 and 5 and Table 5. Figures 4 and 5 show the results for the step-up method and the step-down method, respectively. If Fig.5 is set upside down, the curves in Fig. 5 almost overlap the curves of Fig.4. Also the local mean age of both experiments are almost the same as shown in Fig.6. There is no difference in the results between the step-up method and the step-down method in cases without recirculation air flow.

Effect of Ventilation Air Flow Rate on Ventilation Effectiveness

Figure 7 shows the effect of ventilation air flow rate on ventilation effectiveness in cases without recirculation air flow. As shown in Fig.7, ε_P decreases with the increase of N_T. However, when N_T exceeds 30[1/h] (Re is around 9000), ε_P is stable at a value of 0.8. It is supposed that the reason for this is due to the change of air flow pattern.

Effect of Recirculated Air Flow on Ventilation Effectiveness (Exp.3)

When N_R is changed from 0[1/h] to 40[1/h] with N_T of 20[1/h], the measurement of the gas concentration is executed every 5 minutes. Figure 8 and Table 6 show the effect of recirculation air flow on the ventilation effectiveness. The gas concentration in the exhaust duct decays rapidly just after the start of injection but slowly afterwards, compared to the case without recirculation flow. When N_R is 20 and 40[1/h], the gas concentration becomes uniformly distributed such as in the case of perfect mixing.

Figures 9,10 and 11, and Table 7,8 and 9 show the distribution of ventilation effectiveness under the conditions of an N_R with 0,20 and 40 of air change rate per hour, respectively. With an increase in the value of N_R, the change of the concentration of measuring points becomes close to each other and indicates the same change as the concentration in the case of perfect mixing. The value of ε_P of every point is almost equal to 1.

CONCLUSION

For the reproducibility of the experiment, the results of the decay curves obtained under the same condition of the ventilation air flow rate are very close. The results of the step-up method and the step-down method give the same local mean age. Concerning the effect of the ventilation air flow rate on the ventilation effectiveness, ε_P decreases with the increase of the ventilation air flow. In the case that N_T is over 30[1/h] (Re is 9000), ε_P becomes stable around the value of 0.8. The effect of the recirculation air flow rate on the value of ventilation effectiveness at the exhaust duct becomes smaller with the increase of the recirculation air flow, and the difference of the gas concentration at each point also becomes very small.

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NOMENCLATURE

- N_T : Air change rate [1/h] (Volumetric air flow rate from the outdoor divided by the volume of room 1)
- N_R : Recirculation air flow rate [1/h] (Volumetric air flow rate from room 3 to room 1 divided by the volume of room1)
- Re : Reynolds number (Length scale is the diameter of an orifice plate. Velocity is expressed as the mean value at orifice plate)
- $\overline{\tau}_P$: Local mean age [min]
- $\overline{\tau}_P$: Nominal time constant [min]
- ε_P : Local air change index
- $C_P(t)$: CO_2 gas concentration at measuring point P and time t [ppm]
- V : Total volume of a scale model with the rooms [m^3]
- Q : Ventilation air flow volume [m^3/h]

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