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Influence of staircase ventilation state on the airflow and heat transfer of the heated room on the middle floor of high rise building

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HIGHLIGHTS

- Experiments are conducted in a scaled building model.
- The flow and heat transfer in the heated room are investigated.
- The staircase ventilation state influence on the heated room.
- The results are useful to understand the safety and energy efficiency of building.

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ABSTRACT

Safety and energy efficiency of high rise buildings have attracted public attention in recent decades. In this paper, a set of experiments was conducted in a scaled building model with 12 floors to study the influence of the staircase ventilation state on the flow and heat transfer of the heated room on the middle floor. The airflow, room temperature and fuel burning rate were investigated. It is found that when the window above the heated room is opened, the vents state below the heated room has a significant effect on the airflow and heat transfer in the heated room. When the vents below the heated room are closed, the single-directional air flows into the heated room owing to the stronger stack effect. And the flame tilt angle is larger and the upper hot smoke temperature in the heated room is low. However, when the windows above the heated room are closed, the vents state below the heated room has little influence on the airflow and heat transfer in the heated room. And, there is two-directional air flowing through the door of the heated room The burning rate of heat source is also affected by the staircase ventilation state, and the variation trend varies with the opened window position and pool size.

1. Introduction

Over the past few decades, high rise buildings have been constructed widely in many cities. Consequently, the safety and energy efficiency of buildings have attracted public attention [1,2]. Generally, there are many vertical channels in the high-rise buildings, such as emergency staircase, elevator shaft and ventilating duct. A number of researchers have studied air flow and heat transfer in the buildings [3–11]. The air flow in the buildings is induced by the mechanical ventilation, external wind or stack effect. The air flow induced by stack effect is the main driver in the vertical channels because of the temperature difference between inside and outside of the building. The stack effect is obvious, especially in the cold climate. The stack effect [12] is the air movement caused by the pressure difference which results from the density difference between inside hot air and outside cold air. Under stack effect, fresh air is sucked into the lower floor and the hot air flows out from the upper floor. Airflow pattern and heat transfer in the building are also affected by the stack effect. So it is important to research the influence of the airflow induced by stack effect on the airflow and heat transfer in the room to improve the safety level and energy efficiency of high-rise buildings.

Many researchers have studied the airflow and heat transfer induced by stack effect in the staircases and vertical shafts in the high-rise building [13–19]. Marshall [13] investigated smoke movement in staircase in a one-fifth scaled model of a five-storey staircase. Harmathy [14] studied the direction and magnitude of air flow in buildings induced by stack effect. However, little attention has been focused on the influence of the airflow induced by stack effect on airflow and heat transfer in the room. Satoh et al.

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[20,21] studied the effect of the airflow induced by stack effect on the heat source located on the ground in a reduced shaft, and discovered that the inlet opening area and position affected the vertical distribution of temperature in the shaft. Shi et al. [22] investigated the influence of the stack effect on airflow and temperatures in the room located on the first floor in a scaled staircase building model. In Satoh's [20,21] and Shi's [22] experiments, the heat sources were located on the first ground. Actually, the heat source could be located on any floor of high-rise buildings. In this situation, the vents state on the lower floor would affect the stack effect magnitude in staircase, which further affects the airflow and heat transfer in the room on the upper floor. To study the influence of the staircase ventilation state on the airflow and heat transfer of the heated room on the middle floor of high-rise building, a set of experiments was conducted in a 1/3 scaled building model. The airflow, room temperature and heat release rate in the heated room were investigated.

2. Experiments

The approach of physical scale modeling is well established and has been used in many researches of the airflow and heat transfer in building space [23,24]. The results of the full scale experiment are very rare and valuable, while the experiment cost is expensive and the results are influenced by the external factor, such as temperature, wind and air humidity. With the increasing size of scaled model, the simulative results are close to those in actual cases. On the basis of the general Froude model [23,24], to get more realistic results, the 1/3 scaled building model [25] was built in our laboratory and used in this paper. The building model consists of the staircase, atria and rooms, as shown in Fig. 1. This model with 12 floors is 12.2 m (high) × 2.6 m (long) × 1.5 m (wide). The first floor is 1.2 m high and the other floors are 1.0 m high. There is a window connecting to the outdoor in each floor of the staircase, with the size of 0.9 m high × 0.7 m wide. Both of the first floor and sixth floor have three doors with the size of 0.6 m high × 0.4 m wide. The left and front sidewalls of the model were made of fire-resistant glass with 12 mm thick for observation purpose, and the other parts were made of steel plate with 2 mm thick. The additional 8 mm thick fireboard was used as the inner lining of the heated room and atria on the sixth floor for thermal insulation.

Heptane pool fire was used as the heat source and located in the center of the heated room on the sixth floor. Pools were placed on an electronic balance (AND KG-10) to record the transient mass with a sampling interval of 0.2 s. Temperatures of hot air in the room were measured by 3 K-type fine wire thermocouples (T1-T3, 1 mm in diameter), located 5 cm below the ceiling of the room, as shown in Fig. 2. The uncertainty of these thermocouples is within 1.5 °C, and response time less than 1 s. The data were recorded at intervals of 0.1 s. Three velocity probes of hot-wire anemometers (Kanomax, KA12) with a vertical interval of 15 cm were installed 5 cm away from the right of 6F door 3 at sampling intervals of 1 s, as shown in Fig. 2. The working environment temperature of the probe is within 5–100 °C and the measurement error is less than 2%. Two Digital Vidicons were used to record the experimental phenomena. Three doors on the 6th floor were always opened in all cases and the three doors on the first floor could be opened or closed. Ambient temperature was 28–30 °C, and the relative humidity was 50–60%. For the same heat source size and ventilation state, each case was repeated once. The measured data of temperature, velocity and fuel mass loss rate in these two cases were compared, and results showed that the data repeatability was good. The experiment details are shown in Table 1.

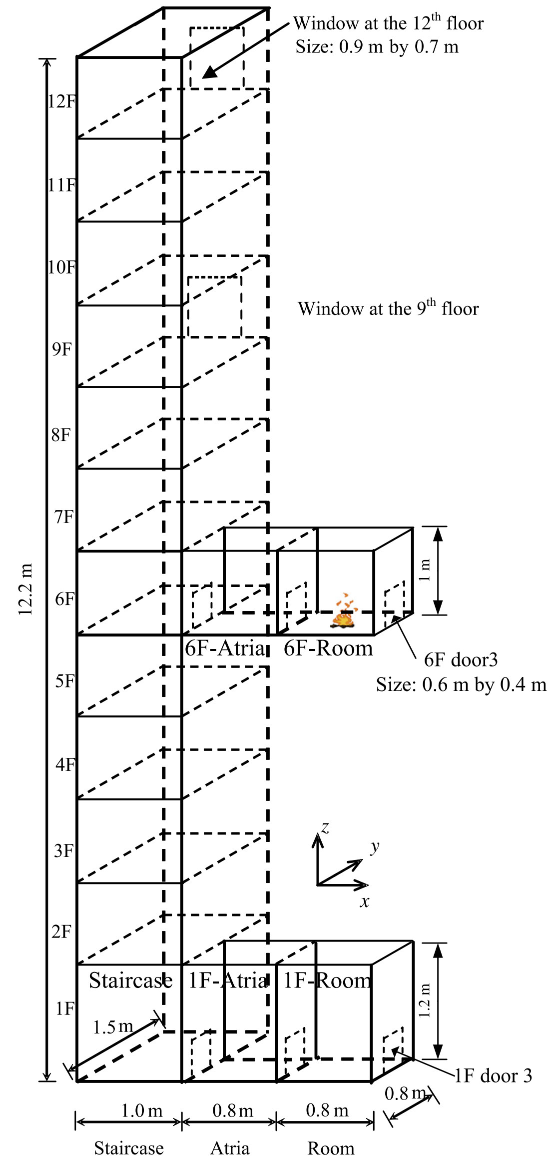

Fig. 1. Schematic of 1/3 scaled staircase building model.

3. Results and discussion

3.1. Influence of the first floor vents state on the airflow in the heated room

After the fuel was ignited, the hot smoke produced by the heat source migrated to the atria and staircase through the door 1 and door 2 on the 6th floor. And then the hot smoke spread upward along vertical staircase and the temperatures in the staircase increased gradually. Stack effect occurred after a few minutes. As a result, the fresh air was sucked into the room through the door 3 on the 6th floor. The velocity of fresh air flowing into the room increased as the increasing of the strength of stack effect. Therefore, the flame tilted toward the staircase due to the fresh airflow. Fig. 3 illustrates the velocities of fresh air flowing into the room through 6F door 3 in case A2 (15 cm pool, 12F window opened, 1F Door 1–3 closed). As shown, the velocities increase continually after ignition, reach a peak at 360 s and almost remain unchanged for about 130 s. The values measured by three velocity probes at the same moment are very close. Then averaged value of three probes could