Study the Performance of Smoke Management with Different Windows During Fire Accident in a Flat Large Space Building

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Abstract. During a fire accident, smoke has been reported to be the main cause of heavy casualties. Hence, smoke management play an important role on escape. Fire Dynamics Simulator software (FDS) was utilized to carry out full scale numerical simulations of fire accident in a flat large space building. According to the simulation result, with the increase of area of natural ventilation vents, the efficacy of smoke confinement didn't change appreciably when only thermal pressure acted on the windows. However, the efficacy became obviously better when both wind pressure and thermal pressure acted on the windows. When the wind pressure played a role on the east external windows and the smoke emission rate remained constant, the efficacy of smoke management was better. The velocity of the exhaust smoke from east external windows had pronounced change of the smoke management. When the velocity inceeased to 2m/s, the efficacy was the best. In addition, when the height of the windows increased in 2m, the efficacy of smoke management became better.

Keywords: Flat large Space Building; Smoke Management; Window; Wind Pressure; Thermal Pressure

1 Introduction

With the development of urban construction, lots of new flat large buildings are built. One characteristic of these buildings is high density of people. Hence, the fire accident commonly results in great economic losses and human death. Once the fire accidents break out, that the smoke diffuse, quickly. Due to thermal pressure and buoyancy, the smoke flow upward and diffuse into different smoke control zoning, fire compartments and floors. Then, human cognitive ability and insight decline rapidly, which lead to bad influence on the escape and rescue[1,2]. British fire and rescue service released the statistics about the fire accident during the year 2019. According to the statistics, 34 percent of the dead died from inhaling toxic gas and 34 percent of the dead died from the combined effect of inhaling toxic gas and burn[3,4]. Hence, the smoke is the main cause

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of injuries and deaths in fire and measures should be adopted to confine smoke diffusion[5,6,7].

The natural ventilation system could play a good role on the smoke management[8]. According to the rules in technical standard for smoke management system in buildings, the natural ventilation system is available when the height of the building is less than 6m and the area of natural ventilation vents is more than 2 percent of the building area. Consequently, when the area of natural ventilation vents is less than 2 percent, mechanical ventilation system must be on operation. The smoke is confined under the comprehensive effect of natural ventilation and mechanical ventilation system, which is called hybrid ventilation. There were lots of research about the hybrid ventilation systems to energy saving[9,10]. Haein Cho evaluated the performance of a hybrid ventilation system by monitoring the IAQ and found the hybrid ventilation system maintained a good level of IAQ while the occupant's window-opening behavior was significantly affected by indoor temperature and CO[11]. Roberto Stasi found earth-to-air heat exchanger was the hybrid ventilation strategy which produced the greatest energy saving in all Italian climatic zones[12].

At the same time, there were some research on hybrid ventilation for fire-induced smoke management. Yan Tong researched a large single space building for smoke control and large eddy full-scale simulations were performed[13]. The research showed under hybrid ventilation of mode 4, back-flow occured under the roof opening when the exhaust velocity reached up to 6m/s, and the maximum smoke temperature and the CO concentration near the door was of the lowest. It indicated that the hybrid ventilation of mode 4 was the best in controlling the fire smoke. Gao Ran researched hybrid ventilation to control fire-induced smoke in a huge transit terminal subway station[14]. Comparing with the conventional mechanical ventilation, hybrid ventilation could inhibit the dispersion of smoke more effectively. The CO concentration in the subway station in the horizontal direction was significantly lower than that with conventional mechanical ventilation. These research were conducted according to the code for fire protection design of building[15].

However, the latest standards for design about smoke management systems is technical standard for smoke management systems in buildings[16]. The comparison between the two standard shows that there is distinct change on the provisions[15,16]. Hence, previous research about the smoke management in flat large buildings may not be met the current standard. So, according to current standard, it has practice significance to study the smoke management in flat large buildings.

In this paper, the fire accident took place on a flat large building and the condition of the smoke management was setted according to the current standard to research the efficacy of hybrid ventilation. The smoke could flow through the doors and windows and the mechanical vents were setted smoke exhaust velocity. The mechanical ventilation system was designed according to the current code, which included the number of the vents, velocities, position and so on. Sensitivity analyses were conducted to find out the influences of natural vents on smoke management when the mechanical ventilation system was on operation.

2 Methods

2.1 Description of the Research Object

The research was conducted in a typical flat large building and the dimension was 80m L x 60m W x 4.5m H, as shown in Fig. 1. Three exits were setted on the north and south sides, respectively and played an important role on leading to outside. The dimensions of the exits were 3m W x 2m H. Eight windows were setted on east and west sides, respectively and the dimensions were 1.8m W x 2m H. All of the windows were the same, but the orientation was different. The vents of natural ventilation accounts for 1.95 percent of the ground area and the mechanical exhaust system must be on operation during a fire accident.

The hung walls were installed and the building divided into six smoke control zoning. The distribution the zoning was as shown in Fig. 1. The sizes of smoke zone п and smoke zone V were both 600㎡ and the sizes of other zones were 900㎡. According to the standard, the rates of mechanical exhaust smoke were 36000㎡/h and 54000㎡/h, respectively. According to the current code, the maximum heat release rate (HRR) was 10MW and the rate of each mechanical exhaust vents must be less than 2700㎡/h[15]. Consequently, there were 18 and 27 mechanical outlets in the corresponding smoke zones and the dimensions for all of the outlets were 300mm x300mm. Furthermore, the inlets were setted and the dimensions of inlets were 700mm x 700mm. During fire accident, outlets played role on exhaust smoke and inlets played role on supplying fresh air. The outlets was set on the top edge of smoke storage area and the inlets was set on the bottom edge of smoke storage area. The vents were distributed uniformly and the distance between the inlet and outlet was bigger than 5m in horizontal direction. There were four thermocouple trees and 19 test points were setted in each of thermocouple trees, which could be used to reflect the temperature at different height.

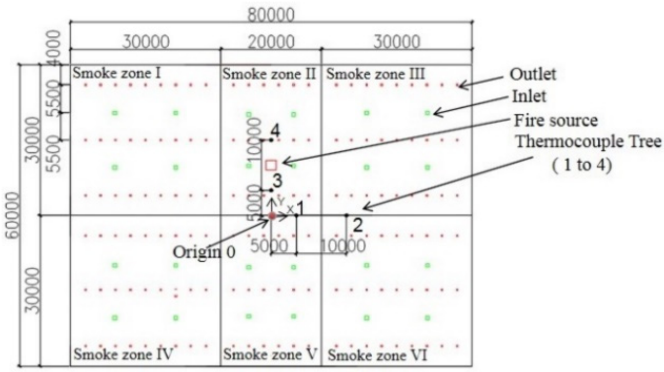


Fig. 1. Mechanical Ventilation system of the building (unit: mm)

The fire source was set in smoke control zoning and the mechanical ventilation system in this zone must be on operation during the fire accident[15]. The outlets must be exhausting smoke and inlets must be sending fresh air. The amount of fresh air must be more than 50% of smoke exhaust level. Hence, the velocity of the outlets was 6.2m/s and the velocity of the inlets was 2.6m/s. The fire source in the paper was based on the setting in the reference[17]. Due to the difference of the HRR between the fire source in this paper and the reference, HRR ration was defined as the ratio of the HRR for different time to the biggest HRR during a fire accident. The HRR ratio of the simulate fire source was be consistent with the fire source in reference and the simulation results agreed well with the experiment results. As show in figure 2.

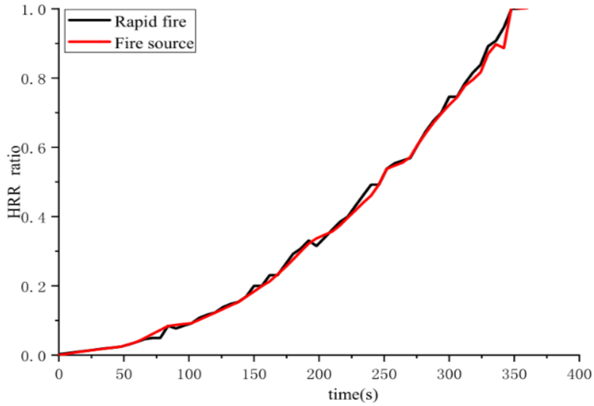


Fig. 2. Comparison of HRR growth rate

2.2 Description of the Research Method

The Fire Dynamics Simulator (FDS) code is developed by the National Institute of Standards to research fire-driven fluid flow and could achieve the visualization[18]. The large eddy simulation(LES) model is adopted to simulate the turbulent fluid field of the smoke. The finite difference method was used to calculate the partial differential equation about conservation of mass, energy, momentum and species and the gas density, temperature and so on are calculated. The software is professional fire simulation software and the simulation result is used extensively in the study of smoke management[19]. In the paper, the software was used to simulate smoke management phenomena with different measure on a full scale building.

The boundary condition of the walls and ceilings of the building were all thermally thick. The bounded materials designated as the concrete and the ambient temperature was set as the default value. The outlets and inlets designated as the VENT and played the role on mechanical ventilation. According to the latest standard, the velocity of outlets was 6.2m/s and the velocity of inlets was 2.6m/s. In addition , the windows designated as the HOLE in the FDS. The fixed air velocity was set to be the boundary condition of the air inlets and outlets and the boundary condition for the six exits was set to be “OPEN”. This boundary condition means the outside air would be free to go inside, and the inside air would also be free to go outside. In LES model, the turbulent Prandtl number Pr, Smagorinsky number Cs and the turbulent Schmidt number Sc were set as 0.4, 0.18 and 0.3. The premixed combustion model was adopt in the research.

The biggest HRR of fire source was 10MW and Ramp-Up time was 400s. The grid system with grid size of 0.740 m × 0.416 m × 0.187 m and the total cell number is 373,248.

2.3 Description of the Research Cases

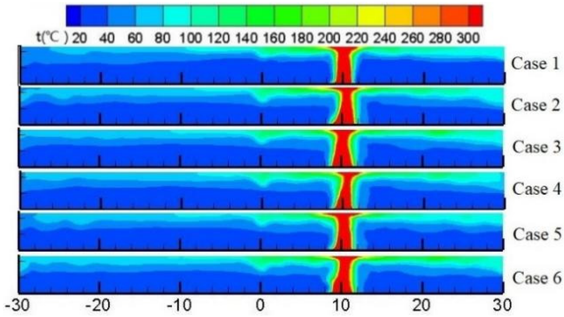
To research the efficacy of the natural vents on smoke management, the cases with different conditions were discussed and comparative analysis was conducted. The conditions of different cases were presented in Table 1. Due to thermal pressure, the gas, for example smoke and air, flowed through the window in cases 2-6. The influence of the area of the windows on smoke management was discussed. However, the windows were subjected to the combine action of thermal pressure and wind pressure in cases 7-12. The wind pressure was affected by outdoor environment and the different directions and velocities of smoke flowing through the windows were discussed.

Table 1. Conditions of cases

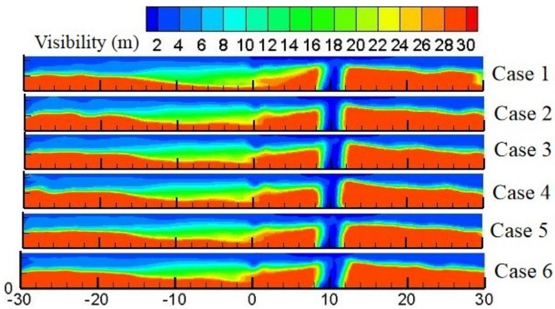
Case	Conditions
1	Mechanical ventilation system shut down; The doors were opening; The windows were opening fully.
2	Mechanical ventilation system was on operation; The doors were opening; The area of windows opening was 0%.
3	Mechanical ventilation system was on operation; The doors were opening; The area of windows opening was 25%.
4	Mechanical ventilation system was on operation; The doors were opening; The area of windows opening was 50%.
5	Mechanical ventilation system was on operation; The doors were opening; The area of windows opening was 75%.
6	Mechanical ventilation system was on operation; The doors were opening; The area of windows opening was 100%.
7	Mechanical ventilation system shut down; The doors and the windows were opening fully; the exhaust smoke velocity of east external windows was 0.5m/s
8	Mechanical ventilation system shut down; The doors and the windows were opening fully; the exhaust smoke velocity of east external windows was 1.0m/s
9	Mechanical ventilation system shut down; The doors and the windows were opening fully; the exhaust smoke velocity of east external windows was 1.5m/s
10	Mechanical ventilation system shut down; The doors and the windows were opening fully; the exhaust smoke velocity of east external windows was 2.0m/s
11	Mechanical ventilation system shut down; The doors and the windows were opening fully; the supply air velocity of east external windows was 1.0m/s
12	Mechanical ventilation system shut down; The doors and the windows were opening fully; the exhaust smoke velocity of the windows was 0.75m/s
13	Mechanical ventilation system shut down; The doors and the windows were opening fully; The height of the windows increased 2m and the exhaust smoke velocity of east external windows was 1.5m/s

3 Results

The fire broke out in a flat large building and FDS software was used to simulate the smoke diffusion with different smoke management measure. As shown in Fig. 3, when mechanical ventilation system shut down and the doors and the windows were opening fully, a mount of smoke was produced and flowed upward due to buoyancy. Then, the smoke impacted with the roof and moved along the roof, which lead to the increase of temperature and reduce of visibility. Due to the smoke accumulation near the roof, the temperature near roof increased clearly and the temperature near the ground stayed almost stable. While mechanical ventilation system was on operation, the temperature near the roof decreased. The reason was that the smoke was exhausted. The distance between the top edge of windows and the roof was 2.2m and the thickness of the smoke layer was less than 2.2m. Hence, the temperature and visibility had small variation with the increase of the area of the windows opening.



(a) Temperature contour



(b)Visibility contour

Fig. 3. Comparison of contour of the plane X = 0m after fire ignited 300 s.

The natural ventilation systems is prone to adverse wind effects, and in some circumstances, it may even negatively affect the consequences of the fire in the building[20,21]. The environment wind may influence the smoke flow behaviour and temperature during a fire accident[22]. For example, due to the high wind, the fire accident develop rapidly and 104 houses were destroyed in Yunnan province[23]. So, the comprehensive action of wind pressure and thermal pressure should be researched. Once there were hot pressure and wind pressure forces upon the windows, that the indoor temperature undergone obvious changes, as shown in Fig. 4. As shown in case 8, the east external windows were under wind pressure and a mount of smoke was exhausted from east external windows. In addition, the west external windows were under thermal pressure and the temperature under the roof became lower. However, when the west external windows were under wind pressure and a mount of air flowed into the room from east external windows, the temperature of personnel activity area was markedly increased. The reason was that the temperature of outdoor air was lower than the indoor temperature. Once the air flowed into the room, the air flowed downward, which inflected the flowing of smoke. Hence, the influence of wind pressure was more apparent than the influence of thermal pressure and the different dection of the wind lead to different diffusion regularity of fire smoke. When the windows played the role on exhausting smoke, it was good to smoke management.

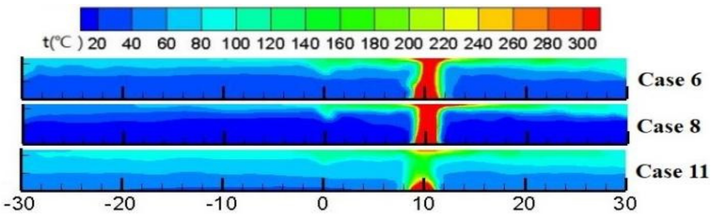
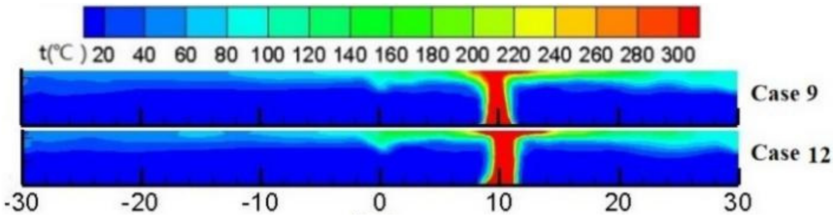
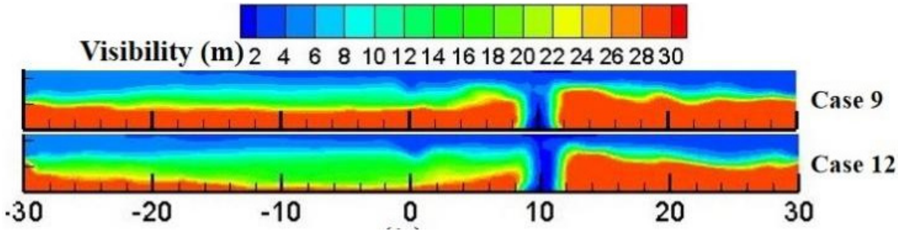


Fig. 4. Comparison of temperature contour of the plane X = 0m after fire ignited 300 s

When the smoke emission rate under wind pressure remained constant and the mechanical ventilation system was on operation, the visibility in case 9 was bigger than that in case 12. Due to the wind pressure, there was smoke exhausted from the east windows in case 9. The air flowed into the building through west windows with the action of thermal pressure, which was similar to the cross ventilation. The distance between the upper edge of windows and the floor was 2.3m, so the affected zone by cross ventilation was close to the ground and the cross ventilation was good to keep the personnel activity area clear. However, both of the east windows and west windows played the role on exhausting smoke in case 11, which was bad to keep the personnel activity area clear. Due to smoke exhausting, the personnel activity area appeared negative pressure and the smoke flowed into the activity area. As show in figure 5.



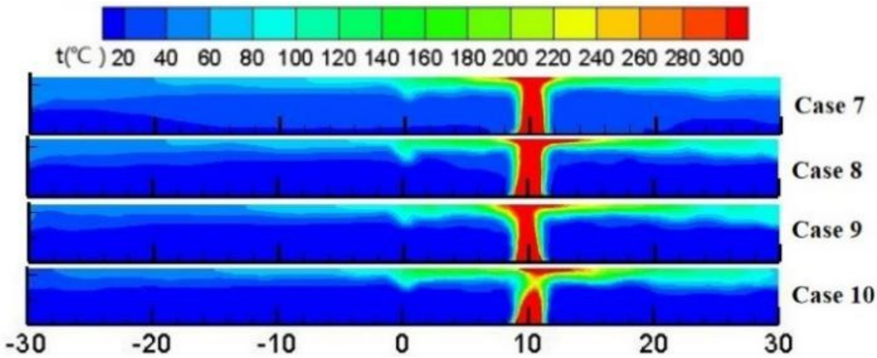
(a) Temperature contour



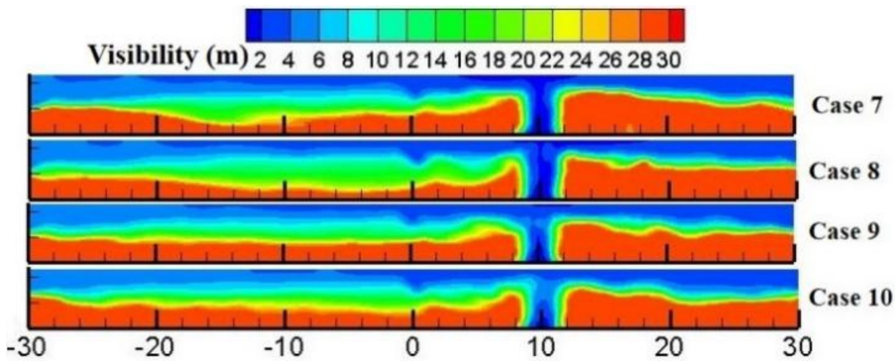
(b) Visibility contour

Fig. 5. Comparison of contour of the plane X = 0m after fire ignited 300 s.

With the increase of the velocity of smoke exhausted from the east windows, more smoke was exhausted and the area of the zone inflected by the smoke diffusion became smaller. So, the visibility near the ground became bigger with the increase of the velocity of smoke exhausted as shown in Fig. 6.



(a) Temperature contour



(b) Visibility contour

Fig. 6. Comparison of contour of the plane X = 0m after fire ignited 300 s.

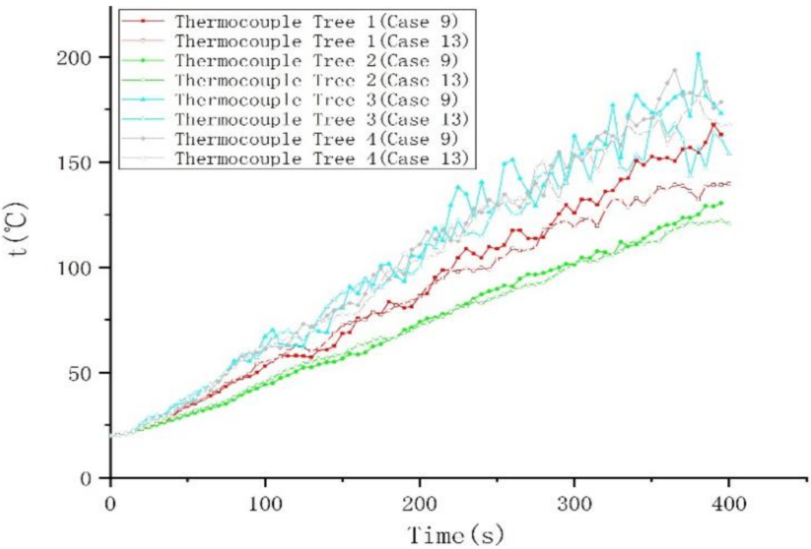


Fig. 7. Comparison of smoke temperature with different ventilation modes

To improve the efficacy of smoke management, the cases 9 was compared with the case 13. The difference was that the windows in case 13 were higher than the windows in case 9 and the height difference was two meters. The highest temperatures for each thermocouple trees were shown in Fig. 7. With the duration of growth phase, more and more smoke was produced and the temperature was also increasing. However, the temperature for the same tree in case 9 was bigger than the temperature in case 13. The reason was that the smoke flowed upward and accumulated under the floor. The windows were higher in case 13, which was good to eliminate more smoke. The comparison of the two cases declared that the height of the windows had obvious implication for the efficacy of smoke management and high position windows should be adopted.

4 Conclusions

Due to the variation of the technical standards about smoke management systems in building, it is necessary to research the efficacy of hybrid ventilation according to the latest standard. A numerical simulation was performed to research the smoke diffusion with the composite effect of mechanical ventilation system and the natural ventilation system. In this paper, the influences of the area of the windows and wind pressure was discussed. According to simulation results, the increase of the area of the windows opening had few influence on smoke diffusion during the initial stages of fire accident when there was thermal pressure playing a role on the windows. Compared with thermal pressure, the wind pressure plaied a more important role on smoke management. The velocity of smoke exhausted from the east windows had obvious implications for smoke diffuse. To improve the efficacy of smoke management, the high position of windows should be adopted.

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