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A Study on the Fire Safety of High-rise Apartments Based on Fire Door Switch and Automatic Fire Extinguishing System

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Abstract

The purpose of this study is to analyse the characteristics and spreading laws of parameters such as fire smoke, concentration of CO, visibility, and temperature at fire scene in high-rise residential buildings under the different conditions of fire doors and automatic fire extinguishing systems. Using Pyrosim to simulate diverse fire scenes in a high-rise apartment with corridors, to analyze the changes in those parameters. The results show that when a fire occurs, closing the fire-fighting corridor will increase the smoke temperature and concentration of CO in the stairwell, and reduce the height and visibility of the smoke layer; the automatic fire extinguishing system effectively suppresses the increase in the temperature of the fire smoke and the sedimentation of the smoke layer. Reasonable setting and operation of the automatic fire extinguishing system could effectively inhibit the spread of fire. Although closing fire corridor can slow down the direct upward spread of smoke through the corridor, it will force the fire smoke into the stairwell, which will seriously affect evacuation through the stairs. Therefore, in order to reduce risks, it is forbidden to close the fire doors of the firefighting corridor and stacking combustible materials in the corridor, Also, intensifying inspections and ensuring the normal operation of the automatic fire extinguishing system are indispensable. Based on the research results, the significance of installing fire-fighting facilities in the construction of high-rise apartments was discussed and proved.

Keywords: *High-rise Apartments, Fire doors, Pyrosim, fire, simulation*

1. INTRODUCTION

In order to alleviate the problems such as rapid increase of population and shortage of land in the process of rapid urban development, high-rise residential buildings with connecting corridors emerged at the historic moment. The corridor building is mainly through the centralized installation of equipment pipe Wells, stairs and elevator Wells on each floor of the unit, and the use of horizontal connection corridors to connect the floor units [1]. The introduction of fire control corridor is helpful to expand the number of safety exits and facilitate emergency evacuation. However, in reality, residents often close and occupy the fire control corridor without permission, and pile combustible materials in the fire control corridor, thus forming fire safety hazards. With the surge of the number of high-rise buildings in the city, and the characteristics of high-rise residential buildings such as complex structure, multiple fire-causing factors and difficult rescue, high-rise building fire

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accidents are increasingly frequent, resulting in a large number of casualties and property losses [2].

AHN (2014) al. conducted experimental and numerical simulation studies on the influence of the opening and closing of Windows in the stairwell of high-rise buildings on fire smoke behavior, and pointed out that closing all Windows would shorten the smoke rise time, but opening Windows would aggravate the fire. [3]

KIM (2016) al. studied the influence of outdoor wind speed and wind direction on the performance of mechanical smoke extraction system for high-rise building fire, and the simulation results showed that the mechanical smoke extraction speed could be reduced by 17% under the condition of wind speed of 16m/s and outdoor wind direction of $\theta = 5°$. [4]

HU (2020) Pyrosim to simulate the impact of fire doors opening and closing in high-rise buildings on the spread of fire, and believed that closing fire doors can effectively delay the spread of fire smoke to high-rise buildings, which is convenient for personnel rescue. [5]

Wang Yu (2020) al. used Pyrosim to simulate the influence of corridor on the fire spread of the facade of high-rise buildings, and the results showed that the height of corridor 1.5m away from the facade and vertical flame fusion height of three Windows as the height of the building external barrier area can effectively slow down the fire spread of the facade. [6]

Dai Changqing (2017). conducted a simulation study on the fire spread in the room of a high-rise residential building and found that opening the door of the room on fire was not conducive to the evacuation of personnel above the fire floor. The aforementioned work focuses on the numerical simulation of high-rise buildings. [7]

Compared with traditional fire experiments, which require a lot of money and time, fire simulation using simulation software can obtain experimental results more intuitively, economically and quickly. In order to explore the law of fire spread in high-rise residential buildings with corridors, Pyrosim simulation is used to analyze the fire spread process under the failure of automatic fire extinguishing system, corridor closure and other factors, aiming to provide theoretical basis for fire prevention and rescue of high-rise residential buildings with corridors.

2. FIRE SIMULATION

In order to master the situation of fire in advance and make emergency evacuation plan and respond to the situation of fire. Based on known experience and computer data, based on temporal variations in fire symptoms and shelter routes, the technology for understanding and improving the safety of people and buildings is called fire simulation. Fire simulation is a mathematical model based on the statistical model of building fire risk assessment and fire risk assessment based on the theories of thermodynamics and fluid mechanics. FDS is a BFRL development of the National Institute of Standards and Technology. Predict the temperature of fire and the flow state of smoke, and conduct modeling analysis of heat, thermal decomposition, flame propagation, smoke movement, fire growth and other phenomena. Through the study of Smokeview fire, the flow state of smoke and other combustion products was visually explained.

2.1 Design Drawings

Taking a high-rise residential building of 3m height and 8 floors with corridor as an example, the simulation modeling is carried out. The floor plan layout is shown in Figure 1. The high-rise residential building contains 2 units, 2 elevators and 2 evacuation stairs, with 4 households on each floor. The units are connected by a fire corridor.

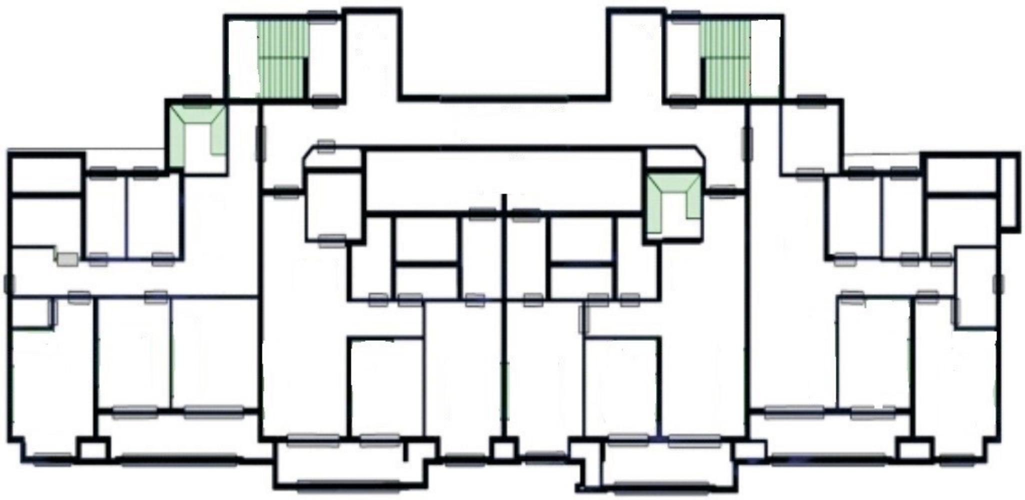


Figure 1. Floorplan

The floor area of the building model is about 498m2 with a height of 3m and a wall thickness of 0.2m, and the area of the air vent at the top is 874m2. The location of the fire source is set in the 4th floor of the residential fire corridor 4m away from the no. 1 stairwell, so as to simulate the fire scene caused by debris piled in the fire corridor. There are two types of fire corridor: closed/unclosed. In the unclosed state, the flow between the corridor and the outside air is not hindered. The maximum opening area of the corridor is 72.8m². The automatic fire extinguishing system adopts water spraying, and the water spraying function temperature is 68 ℃ according to the Design Specification for Automatic Sprinkler System [8].

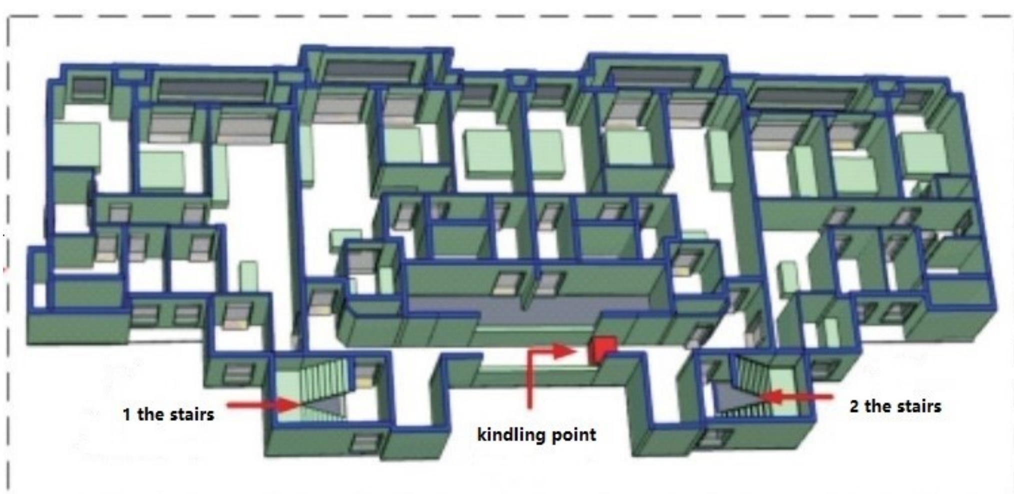


Figure 2. Fire point setting diagram

3. FIRE SIMULATION CONFIGURATION

3.1 Model Settings

The fire growth type is set as t2 growth type [9]. The simulated fire scene in this paper is that the fire caused by the accumulation of sundries in the corridor is caused by plastic foam and wood pallet bracket. According to the literature, fast fire should be selected. [10] The fire source area is 1m x 1m, and the power of the fire source is 1500kw/m2. The combustion reaction substance is polyurethane, and the fire simulation time is 600s. The size of the simulated grid was set as 0.5m×0.5m×0.5m [11], with a total of 244,720 grids. All doors and Windows in the building are set to open, considering the most adverse principle of fire simulation. Four simulation scenarios are set for two fire hazards: closed fire corridor and failure of automatic sprinkler device. See Table 1 for specific fire simulation scenarios.

Table 1. Fire simulation scene-setting for high-rise residential buildings with corridors

Scenario	Fireproof door	Automatic sprinkler system
Scenario A1	close	close
Scenario A2	close	open
Scenario A3	open	close
Scenario A4	open	open

A total of two observation stations were installed in the model. The measuring devices such as observation station No. 1 and thermocouples were located at 1.5m on the dot and used to measure the fire field ceiling temperature, CO mass concentration, and altitude data of the smoke layer. The 2nd measuring device is located 1.5m higher than the floor of the stairs below the 1st stair (6th floor) fire door. Refer to Table 2 for detailed setting of the observation station.

Table 2. Monitoring point and detection device settings

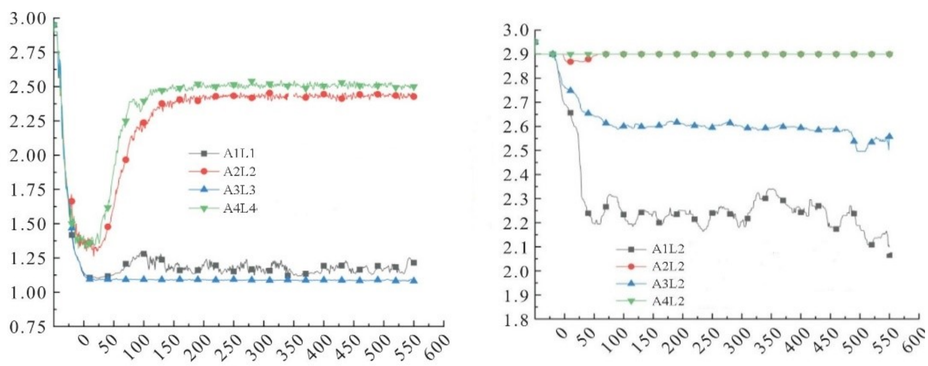
Monitoring stations	Contents	Criteria
Monitoring point 1	Inside the fire corridor (Height Z = 29.5m)	Thermocouple: T1 Gas phase detection device :(smoke layer height detection L1, CO mass concentration detection C1)
Monitoring point 2	1 the stairs (Height Z = 28.5m)	Thermocouple: T2 Gas phase detection device :(smoke layer height detection L2, CO mass concentration detection C2)
Monitoring point 3	Inside the fire corridor (Height Z = 31.5m)	Thermocouple: T3 Gas phase detection device :(smoke layer height detection L3, CO mass concentration detection C3)
Monitoring point 4	2 the stairs (Height Z = 28.5m)	Thermocouple: T4 Gas phase detection device :(smoke layer height detection L4, CO mass concentration detection C4)

4. RESULTS AND DISCUSSION

4.1 Analysis of The Altitude and CO Concentration of The Smoke Layer

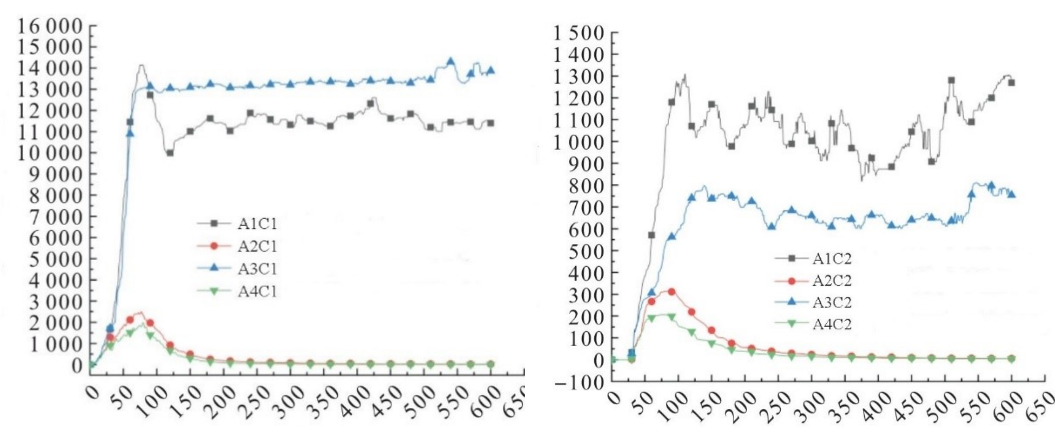
Figure 3 shows the smoke layer variation curve with temperature at two monitoring points under four fire scenarios. After the fire, a large amount of smoke was rapidly generated at the No.1 monitoring point. As shown in Figure 3(a), the smoke volume generated in A3 fire scenario is the largest, and the height of smoke layer finally stabilizes at 1.12m. In A2 and A4 fire scenarios, under the action of automatic fire extinguishing system, the height of smoke layer gradually rises after 50s, and finally stabilizes at 2.4m and 2.5m respectively.

Figure3 (b) shows the height change of smoke lighting gas layer monitored by No. 2. In A1 fire scenario, the height of smoke layer decreases rapidly after 25s and finally stabilizes at 2.2m, lower than that in A3 fire scenario. Note In the closed condition of the fire corridor, the smoke generated from the ignition point poured into the adjacent stairwell, making the height of the smoke layer in stairwell No. 1 in the A3 fire scenario lower than 2.5m, seriously affecting the safe evacuation of personnel. In A2 and A4 fire scenarios, due to the action of automatic fire extinguishing system, the height of smoke layer decreases to 2.85m at 25s, and finally stabilizes at 2.9m. From the monitoring of the change in the height of the gas layer, it can be seen that after the fire occurred, a large amount of smoke was rapidly generated at the location of the fire source. As the fire point is located in the fire corridor, a large amount of smoke generated by the fire point cannot be eliminated directly under the condition of the closed fire corridor, which leads to the fire smoke pouring into the stairwell and seriously affects people's escape through the stairwell. The participation of automatic fire extinguishing system can effectively reduce the generation of fire smoke.



(a) Monitoring point 1 (b) Monitoring point 2

Figure 3. Time change curve of smoke layer height at different monitoring points in 4 fire scenarios



(a) Monitoring point 1 (b) Monitoring point 2

Figure 4. Variation curve of CO concentration with time at different monitoring points in 4fire scenarios

Exposure to 8000mg·m-3 CO may result in death within 10 to 15 minutes. Figure 4 (a) shows the curve of CO mass concentration at the No.1 monitoring point over time. Under the four fire scenarios, the mass concentration of CO above the ignition point increases rapidly within 75s. Under the A3 fire scenario, the mass concentration of CO generated by fire is the highest, reaching 13000mg·m-3. In A2 and A4 fire scenarios, the amount of CO generation gradually decreases after 75s, indicating that the automatic fire extinguishing system has a significant effect on reducing the generation of CO toxic gas in fire. Similar to the height change of flue gas layer, the change of CO mass concentration at no.2 monitoring point is shown in Figure 4 (b). In the case of A1 fire, due to the closure of the fire corridor, the smoke generated from the ignition point poured into the adjacent stairwell, making the CO mass concentration in stairwell No. 1 the highest in the case of A1 fire. By comparing the A1C2 and A2C2 curves, the automatic fire extinguishing system can reduce CO generation in the fire. However, the unsealed fire corridor is more conducive to flue gas discharge and reduce the CO concentration in the adjacent stairwell.

5. CONCLUSION

This study analyzed the simulation of the fire scene of high-rise residential buildings with corridors under the closed corridor and the participation of automatic fire extinguishing system, and the analysis results are as follows:

(1) In the case of a closed corridor fire, the ignition point located in the corridor because the ventilation is reduced oxygen levels go down, reduce the amount of smoke production of smoke the temperature of the flue gas layer produced the mass concentration of CO is lower than that of unsealed corridor fire the height and visibility of the corresponding smoke layer are higher than that of the unsealed corridor fire scenario.

(2) The closed fire corridor cannot make the smoke generated by the fire point be discharged out in time. Although it slows down the smoke spreading directly to the upper layer through the corridor, a large number of smoke will instead pour into the escape stairs and other Spaces. At the same time, the temperature and CO amount in the stairwell increase, and the height and visibility of the smoke layer decrease, which seriously affects the evacuation of personnel.

(3) Automatic fire extinguishing system can quickly reduce the temperature of the fire site, creation quantity of CO, Improve the visibility of the fire site, effectively inhibit the spread of fire smoke, conducive to timely evacuation. The reasonable configuration and effective operation of automatic fire extinguishing system is an indispensable and important part to ensure the fire safety of high-rise residential buildings.

(4) It is suggested that the grass-roots emergency management units and residential property to strengthen the popularization and publicity of fire safety knowledge, from the source to eliminate the phenomenon of closing the fire corridor and stacking combustible materials in the corridor; Strengthen fire inspection to ensure the normal operation of automatic fire extinguishing system. Regular fire drills are recommended to help residents familiarize themselves with escape routes and methods.

Due to the limitations of this study, the velocity of the smoke flow to the upper layer has not been verified. The effects of smoke in a fire are the biggest causes of casualties at the site. As a future research project, it is necessary to use fire simulation to continue to study smoke diffusion and movement during fire to improve evacuation time.

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