Analysis of the indoor fire risk based on the Pyrosim simulation

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Abstract: In order to study the effects of different fire conditions on the indoor fire process, this paper uses Pyrosim to perform a fire simulation of a simple indoor room in the paper, we have compared and analyzed the changes of the temperature, the smoke layer height, and the heat flow in two different conditions with the window and door being open, or with the window closed but the door opened 30 seconds later after the fire broke out. Pyrosim simulation results show that in the first 30 seconds of the fire outbreak, the fire development has nothing to do with the opening and closing of doors and windows. In the middle and late stages of the fire, when the door and window are fully open, the temperature and heat flow of the simulated room are low, and the height of the smoke layer from the ground is high. In the simulated room, with the window closed and the door opened after 30 seconds, the maximum temperature in the simulated room was about 10 higher than that in Condition 1.

1.Introduction

People call the phenomenon of catastrophic burning uncontrollable in space and time fire. Among all kinds of disasters, fire is one of the most common and pervasive disasters that threaten people's safety and social development. There are construction fire, jungle fire, vehicle fire, et al., but among all kinds of fires, construction fire occurs the most frequently and causes the most damage[1].

Studying the law of occurrence and development of fires and predicting their hazards are the key to effectively preventing and extinguishing fires in time. In the research work of fire safety, due to the high cost of fire test and the certain danger, it is very difficult to conduct real fire test. Therefore, the use of computer simulation to analyze fire problems also has certain research value. The key point of the computer model is to establish a fire model that is similar to the indoor fire site, so that the development process of fire can be intuitively analyzed and understood[1]. Cui Tiejun et al.[2] took a subway station as an example, used fire smoke simulation software to study the temperature change and the distribution of smoke when the fire broke out; Liu Xiao et al.[3] used FDS to simulate the fire dynamics of the rooms and corridors of a high-rise residential building, and obtained the best evacuation time by testing the smoke concentration, CO concentration, temperature and visibility of different measuring points; Glasa[4] et al. found that the cinema hall was the most dangerous place through the established fire scene, and found that the curved ceiling was the most dangerous place for the audience in the event of fire. Based on this experimental conclusion, the cinema fire model was
created through FDS\cite{5}. Fu Yigang et al.\cite{6} carried out fire scene simulation for a series of basic models, analyzed and compared the numerical changes of temperature, visibility, smoke concentration, CO concentration and other indicators, and found that for different indicators of a single model, visibility first reached the critical value, followed by temperature. Gong Zhencong et al.\cite{7} used FDS to simulate a fire in a hot pot restaurant in Nanjing, analyzed the smoke diffusion, temperature and visibility in the store, and found the best evacuation time, and found that the fire alarm equipment can shorten the time for people in the store to find a fire and increasing the openness of the store can increase the safe evacuation time of personnel; He Mingli et al.\cite{8} found that in the early stage of fire, it is the best time to put out the fire, when the fire enters the burning stage of open fire, it will be difficult to put out the fire, but the sprinkler system and smoke exhaust system will control the fire obviously.

In this paper, FDS software is used to study and analyze the change process of factors such as temperature, smoke layer height, heat flow and other factors caused by indoor fires, and obtains the best escape time under different working conditions.

2. Model establishment

2.1. Simulation room overview
The size of the fire simulation room is 3.6×5.2×2.9m. The size of the door is 900×2100mm; the size of the window is 2100×1800mm, which is 600mm high from the ground. The bed, wardrobe and bedside table are mainly placed in the room. The size of the bed is 1.5×2.0m and the height is 0.45m. The bed is covered with a mattress and several sets of futons. The size of the wardrobe is 0.5×1.1m and the height is 1.9m. There are also two 0.3×0.4×0.5m bedside tables. The floor plan is shown in Figure 1.

![Figure 1. Floor plan of the fire simulation room](image)

2.2. Fire scene setting
This paper simulates a simple separate room, in which the main fuel is the bed body and the wardrobe, which is full of clothes. Figure 2 is a 3D rendering of the model layout in the room. The wall of the room is 240mm thick, and the surface is daubed with 20mm cement mortar. The material is layered. Wardrobe, bedside cabinet and bed body are made of wood with a density of 570kg/m3 and the heat of reaction is 430kJ/kg. The mattress and bedding on the bed body are layered, with the first layer of 2mm thick fabric and the second layer of 100mm thick foam.
According to the requirements of the FDS software, the cell size should conform to the modulus of 2U, 3V, and 5W when dividing the grid, and U, V, and W are all integers [9]. Therefore, in order to achieve the best simulation accuracy, the simulation object mesh is divided into $54 \times 81 \times 40$, and each small square is a parallelepiped of 0.1m [10].

The fire source is set on the side of the bed closes to the quilt, the fire source area is 0.2m$\times$0.2m, the initial temperature is 1000$^\circ$C, the heat release rate on the surface is 1000Kg/m$^2$, and combustion heat droplets are injected. This paper, mainly discusses and analyzes the period of time from the moment when the fire produces an open flame to the 600s after the burning reaction material is polyurethane, while ignoring the smoldering stage before the open flame [5].

The room is equipped with thermocouple detection equipment, interlayer detection equipment and heat flow detection equipment. The distribution of measurement points is shown in Figure 3(a). The two working conditions of fire are shown in Table 1. In order to obtain the temperature cloud map in the room, three temperature slices are set along the x direction. As shown in Figure 4, slice x=1.3m is set along the head of the bed, slice x=2.6m is set along the end of the bed, and slice x=4.1m is set along the door set up.

| Working condition of the name | Description                      |
|-----------------------------|----------------------------------|
| Condition 1                 | Open all doors and windows       |
| Condition 2                 | Close the window and open the door after 30s |
3. Simulation results and analysis

3.1. Temperature

Figure 3(b) shows the temperature comparison curves of different positions in the room under the two working conditions. From Figure 4(a) ~ (e), it can be seen clearly that the temperature from point 1 to point 5 in the room after the fire will appear an inflection point in the 50s, the temperature before the 50s will rise rapidly and reach the inflection point, and the temperature growth rate after the 50s will gradually slow down and tend to balance [5]. In the first 30s, the temperature in the room under the two working conditions is the same. After 30s, the window of the room is closed and the door is opened after 30s. Compared with the Condition 2, the temperature of Condition 1 is about 10℃ lower.

The results show that in the first 50s of the fire, the temperature increase in the room has nothing to do with the opening and closing of the door and window. Because heat is generated in the short term after the fire and cannot be dispersed in time, resulting in a rapid rise in the temperature of the room [5]. But then, since the door and windows in Condition 1 are all open, the heat will be released through the door and windows, so the room temperature in Condition 1 is obviously lower than that in Condition 2.

The difference between measuring point 6 and measuring point 1 to measuring point 5 is that the temperature change trend of measuring point 6 under Condition 1 is not great. In Condition 1, when the door and window are all opened, the temperature of measuring point 6 is mostly around 25℃, and...
the maximum temperature is only 40°C. Condition 2, means that the window is closed and the door is opened after 30s, the temperature change trend of measuring point 6 and measuring point 1 to 5 is very similar. 50s before the fire, the temperature increased rapidly and reached the inflection point around 50s. After the turning point, the temperature growth rate gradually level off.

Because the measuring point 6 is located near the door, it is greatly affected by the opening and closing of the door and windows. When the door and windows are all opened, the heat in the room is emitted through the door and windows, and the measuring point 6 is only close to the door and can contact the external air. When the door and windows are all opened, the indoor air back flow will be formed to reduce the indoor temperature. When only the door is opened and the windows are closed, there is no reflux in the room, and the heat cannot be well dissipated.

The temperature cloud diagrams at different positions of the two working conditions at t=510s are shown in Figure 5-7. We can see clearly from the figure that the temperature of Condition 1 is significantly lower than that of Condition 2 by 10°C, and the maximum temperature near the door opening in the room is 5°C lower than the temperature near the bed. The main reason is that the ignition point is located. The bed body is close to the side of the bedding, the bed body is the main burning material, and the temperature near the door hole is affected by the external environment, and the heat will be dissipated along the door and windows, thereby reducing the temperature near the indoor door.
3.2. Height of smoke layer

In addition to temperature and harmful gases during a fire, smoke will also affect the safety of personnel evacuation and fire rescue. The particles in the smoke can completely block visible light. When the smoke diffuses, the intensity of visible light will be greatly weakened due to the occlusion of smoke particles, and the visibility is greatly reduced, and the smoke has a great stimulating effect on human eyes, making it impossible for people to open their eyes, thereby affecting the speed of evacuation [11-12]. The horror of smoke is not only its physical harm to people, but also often causes psychological panic, especially when the fire is large, flames and thick smoke appear in the holes of doors and windows, which will cause greater panic. And cause great obstacles to evacuation [13].

Studies have shown that when the height of the smoke layer is lower than 2.5m, it will seriously affect the escape of personnel; personnel cannot complete the escape activities when the height of the smoke layer is lower than 1.5m. We can see that the flue gas change trend under the two working conditions is the same from the comparison curve of the smoke layer height in Figure 8. It drops quickly to the lowest point after 30s, and the Condition 2 fluctuates greatly in the 30s after the door is opened and then flattened out. The two conditions have the same risk in the first 30s of the fire. However, in the later period when the door and windows are all opened, the door and windows opening can diffuse the smoke outward, and the smoke of the Condition 2 can only diffuse through the door opening. Therefore, after 30s, the height of the smoke layer when the door and windows are fully opened is lower than the height at which windows are closed and the door is opened at 30s.

It can be seen from Figure 8 that the best escape time for Condition 1 and Condition 2 is 30s before the fire. After 30s, the height of the smoke layer in Condition 1 reaches about 1.8m, and personnel escape will be affected; the height of the smoke layer in Condition 2 is lower than 1.5m, and indoor personnel escape will not be completed.

3.3. Heat flow

Figure 9 shows the heat flow of the door after the fire occurs in the two working conditions. The results show that when the door and window are all opened, the heat flow of the door is always at the
same level, and there is almost no change; the change trend of the Condition 2 before the door is opened is similar to that of the Condition 1, after the door is opened, the heat flow rises rapidly to the maximum value and then decreases, then tends to flatten. Because the window can diffuse the heat flow outward, the heat flow in the room when the door and windows are fully opened is much lower than the heat flow of the door. The maximum heat flow of the door is 30kW, and the heat flow at equilibrium is 15kW.

4. Conclusion
By comparing the dynamic simulation results of two fire conditions in the simulated room, the conclusions are as follows:

1) The opening and closing conditions of doors and windows will not affect the temperature change within the first 30s of the fire in the room, and the fire hazard is roughly the same in the two working conditions. In the later stage of the fire, the overall temperature in the room is lower than Condition 2 because all the door and windows are opened. The maximum temperature of the room under the two conditions differs by 10°C, among which the maximum temperature is mainly distributed near the bed body, while the temperature in other places differs by about 5°C.

2) By comparing the height of the smoke layer under the two working conditions, it can be found that when the door and window are fully opened, the smoke can be well diffused through the door and window, which is more conducive to escape.

3) In the two working conditions, the cumulative heat flow of doors, windows and rooms is the same in the first 30s of the fire. After 30s, the cumulative heat flow balance of the room in Condition 2 is about 5kW higher than that in Condition 1. Part of the heat is mainly used to raise the temperature in the room, and a small part of the heat is diffused out through the door and windows.

4) When some rooms with a lot of indoor furniture such as bedrooms catch fire, because there are more combustibles in the room, after a period of smoldering, the smoldering stage is generally difficult to be found, and the fire will burst. The fire after the explosion is generally difficult to control, and it will be even more difficult to escape at this time.

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