

Numerical Simulation of Fire in Library Atrium Based on FDS

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Abstract. In order to prevent the fire accident in the comprehensive library, using the fire dynamic simulation software (FDS), taking a comprehensive library of a university as the research object, and taking the atrium self-study area on the second floor with the fastest smoke diffusion as the fire point, the temperature, smoke flow, visibility The distribution characteristics of CO and CO₂ volume fraction are analyzed by numerical simulation, and the variation characteristics of each parameter are obtained. The simulation results show that the temperature, visibility and smoke layer height near the fire source have a great impact on the safe evacuation in the process of fire development. Among them, temperature has a decisive impact on personnel safety in the range of about 1m from the fire source. In the range of 5-10 m, visibility has the greatest impact on safe evacuation. The closer to the fire source, the faster the height of smoke layer decreases.

Keywords: University Library; FDS; fire simulation; parameter analysis.

1. Introduction

As the center of school information resources, the university library is a large-scale densely populated place, and the library contains a large number of flammable and combustible materials, once a fire occurs, the harm and loss caused by it will be immeasurable, therefore, it is of great significance to study the fire development process of the university library. At the same time, the fire experiment is destructive, coupled with the complex structure of the library, the full-scale experiment is costly, time-consuming, and dangerous. Therefore, it is a good research method to use computer to numerically simulate the process of fire. Ma et al. [1] used FDS to establish a full-scale model of the library, and obtained the time when the fire reached the danger, and judged whether the safe passage met the safety evacuation needs by comparing it with the actual evacuation time. Li et al. [2] used Pathfinder to simulate the emergency evacuation of university buildings, and proposed an optimization scheme for the safety layout of the school through the evacuation results under different conditions. Liu et al. [3] used PyroSim to simulate the fire in high-rise office buildings, and obtained the most affected areas of fire development in high-rise office buildings, so as to further optimize the evacuation in different areas and make the simulation closer to the real situation.

In summary, this paper takes a university library as the research object, collects the real size and internal structure of the library, and uses FDS numerical simulation to analyze the distribution and change characteristics of various factors in the fire under set working conditions, so as to provide a favorable basis for the safe evacuation of the university library.

2. Numerical simulation of fire

2.1 FDS Basics

FDS is a building fire simulation software based on computational fluid dynamics (CFD) and developed by the National Institute of Standards and Technology (NIST) in the United States, whose main function is to use field simulation to solve the spatial distribution of state parameters in the fire process and their changes over time [4-5]. The software's accurate simulations are based on the setting of parameters and the solution of basic governing equations, which are expressed as follows:

The equation for conservation of mass is:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \vec{u} = 0 \quad (1)$$

The equation for the conservation of mass in the direction of each velocity component is:

$$\frac{\partial(\rho \vec{u})}{\partial t} + \nabla \cdot \rho \vec{u} \vec{u} + \nabla p = \rho g + f_b + \nabla \cdot \tau_{ij} \quad (2)$$

Equation for conservation of energy:

$$\frac{\partial(\rho h_s)}{\partial t} + \nabla \cdot \rho h_s \vec{u} = \frac{Dp}{Dt} + q^m - q^m_b - \nabla \cdot q^n + \varepsilon \quad (3)$$

The equation of state of the gas is:

$$p = \rho R_g T \quad (4)$$

Where: ρ is the density, kg/m³; t is the time, s; \vec{u} is the velocity, m/s; p is the pressure, Pa; g is the gravitational acceleration, m/s²; f_b is the external forces acting on a unit volume, N/m³; h_s is the enthalpy, J; q^m is the rate of heat release per unit volume in a chemical reaction, kW/m³; q^m_b is the transfer the energy of the evaporated droplets, J; q^n is the heat fluxes for thermal conductivity and radiation, kW/m²; ε is the diffusion terms; R_g is the gas constant, J/(kg·K); T is the temperature, K; τ_{ij} is the viscous stress tensor.

2.2 Meshing

In FDS fire simulations, all numerical solutions are mesh-based [6-7]. The size of the grid is determined by the ratio of the characteristic diameter of the ignition source (D^*) to the nominal size of the grid element [8]. The formula for calculating the characteristic diameter of the ignition source is as follows:

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}} \right)^{\frac{2}{5}} \quad (5)$$

Where: \dot{Q} is the heat release rate of the ignition source, kW; ρ_∞ is air density, kg/m³; c_p is the specific heat capacity of air, kJ/(kg·K); T_∞ is the ambient temperature, K; g is the acceleration due to gravity, m/s².

It is found that when the value of D^* is in the range of 4-16, the numerical simulation process can describe the development of the flame well. In this paper, the heat release rate of the ignition source is set to 4 MW, and the grid size range near the suitable ignition source can be obtained by calculation. In order to improve the simulation accuracy and the utilization rate of computing resources, the grid size near the fire source is 0.25m × 0.25m × 0.25m, and the grid size away from the fire source is 0.5m × 0.5m × 0.5m.

2.3 Physical model building

Based on the field survey and the library's CAD design drawings, the physical model was constructed using PyroSim software, as shown in Figure 1. The library is V-shaped as a whole, and the front view appearance is in the form of a staircase, the first floor to the fifth floor is mainly composed of a borrowing area and a self-study area, and the sixth floor is composed of a comprehensive service center and office area. The library covers a total area of 24,800 square meters, with a total of 6 floors, a ceiling height of 4.5 meters, a ceiling thickness of 1.5 meters on each floor, that is, a net height of 3 meters on each floor, and a total of 3,641 reading seats. The main body of the library is built on the mountain, with the main entrance on the first floor and the back door on the third floor.

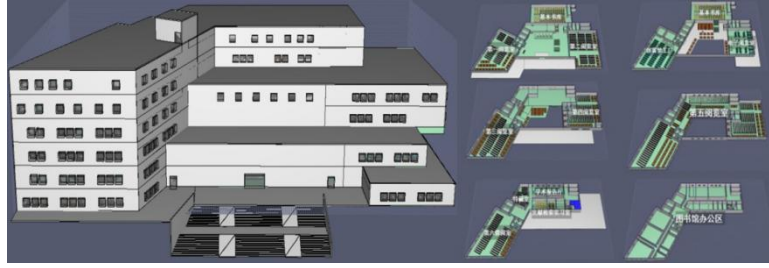


Fig. 1 Library floor plan (left) and floor plans (right)

2.4 Fire scene settings

2.4.1 Ignition source conditions and working condition settings

The Heat Release Rate (HRR) refers to the amount of heat released by combustion per unit of time under specified conditions, and is an important parameter for assessing fire hazard [9].

In this study, unsteady state fire is used, and the relationship between the growth rate of fire heat release is shown as follows:

$$Q = \alpha t^2 \quad (6)$$

Where: Q is the heat release rate of the ignition source, kW; α is the fire growth coefficient, kW/m²; t is the time, s.

Due to the large number of wooden tables and chairs, books and electrical equipment in the atrium study area on the second floor of the library, the risk of fire smoke spread is greatest when a fire breaks out here. Therefore, the self-study area in the atrium on the second floor is set on fire, and the fire source is shown in Figure 2. Because the structure of the self-study area in the atrium on the second floor is similar to that of the office, the fire source growth type of the atrium on the second floor is selected as rapid fire during the simulation, and the growth coefficient is 0.0469 according to the international standard "Fire Safety Engineering Part 4: Setting Fire Scenarios and Setting Fire Options" (ISO/TS16733). In addition, because the structure of the library is closer to that of a warehouse with sprinklers, the fire heat release rate is set at 4 MW according to the Technical Regulations for Smoke Prevention and Exhaust in Civil Buildings [10].



Fig. 2 Schematic diagram of fuel point on the second floor

2.4.2 Arrangement of measurement points and lines

The layout of the survey points and survey lines in the atrium on the second floor is shown in Figure 3. Firstly, a temperature survey point is set above the center of the fire source to measure the temperature change of the center of the fire source, and then a survey point is set every 5 m along the evacuation direction of staircase 1, and these survey points are used to detect the values of temperature, CO concentration, CO₂ concentration and visibility at a height of two meters from the floor of the second floor, and the same monitoring points are also set in staircase 1 and staircase 2. In Figure 3 (right), a survey line is set every 5 m below the self-study area on the third floor on the left side of the fire source, and a survey line 6, a survey line 7 and a survey line 8 are set up in the atrium area on the right side of the fire source, and the changes in the height of the smoke layer at different locations are analyzed through these survey lines.

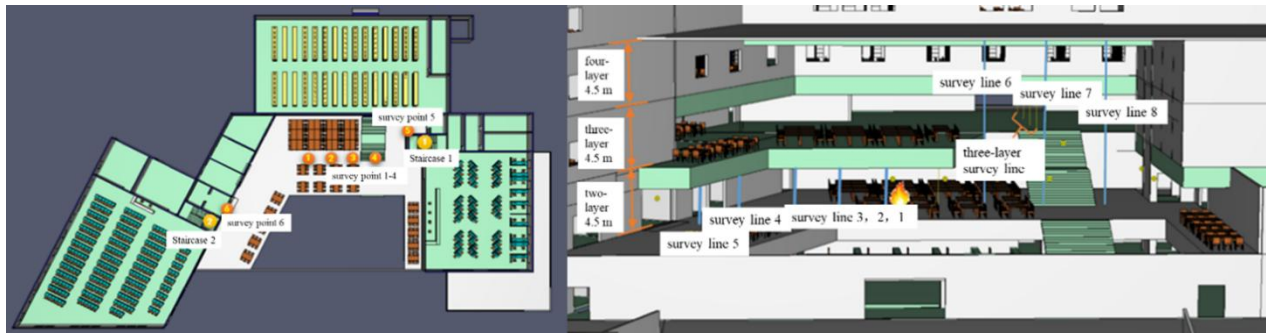


Fig. 3 The view of survey points and survey line layout

2.4.3 Simulated fire time

Considering that the area of the book reading area and the electronic reading room is large, the length of the evacuation route is within tens of meters, and the crowd is mainly young and middle-aged, and the daily flow of people is between 2500-4400 people, the personnel speed is set to 1.8 m/s and the simulation duration is set to 600 s.

2.4.4 Boundary Condition Setting

According to the actual research of the library, the indoor and outdoor ambient temperature is set to normal temperature, and the indoor and outdoor pressure is also atmospheric pressure, except for the door of the special purpose room, the other doors and windows are naturally open, and the surface properties of walls, floor tiles and stairs are set to thermal insulation and inert.

3. Simulation results and analysis

3.1 Safety evaluation criteria

In the numerical simulation of FDS fire, the parameters of temperature, visibility, smoke layer height, CO volume fraction and CO₂ volume fraction have an important impact on personnel evacuation. In this paper, the above factors are used as the basis for judging safe evacuation according to the actual situation, and the evaluation table is shown in Table 1.

Table 1. Safety evaluation criteria

Influencing factors	Threshold	
Temperature/°C	2 m (height)	< 60
Visibility/m		> 10
Smoke layer height/m		< 0.5×10 ⁻³
CO volume fraction/%	< 0.06	
CO ₂ Volume Fraction/%	< 3	

3.2 Analysis of fire simulation results

3.2.1 Temperature parameter analysis

In the fire scene, a large amount of high-temperature air will be generated, and when excessive high-temperature air is inhaled into the human body, the respiratory system of the human body will be damaged, resulting in the inability to carry out normal evacuation. From the analysis of the central temperature of the ignition source at the ignition point and the measurement point at a height of 2 m from the ground, it can be seen that at 322 s, the central temperature of the ignition source reaches the maximum value of 686 °C, and the closer to the ignition source, the higher the temperature. At a height of 2 m, the impact range of the initial phase of the fire is relatively small. In the middle stage of fire development, the temperature rise trend was most obvious at 1 m away from the fire source, and the maximum temperature reached 94 °C at this stage, and exceeded the

human safety temperature by 60 °C after 250 s. When the fire reaches the plateau stage, with the further diffusion of smoke and heat transfer, the temperature of each survey point in the atrium on the second floor fluctuates up and down at a fixed value. Due to the particularity of the building structure, the atrium on the second floor is an extended platform, so the temperature of other survey points does not exceed the critical value and is always kept below the safe temperature.

3.2.2 Visibility and smoke layer height parameters analysis

By analyzing the distribution of visibility at 2 m from the ground in the process of fire, it can be found that after 48 s of fire, the visibility within 5 m and 10 m from the fire source decreases rapidly, and the visibility is lower than 10 m after 78 s and 125 s, respectively, and after 114 s, the smoke from staircase 2 begins to spread to the third floor, and after 140 s, the visibility is less than 10 m, and the distance from the fire source is 15 at the same time. The visibility at position m is almost unaffected because the platform on the third floor is partially unobstructed by buildings, and the smoke will drift directly to the roof of the fourth floor, so it is almost unaffected, and with the passage of time, the smoke is further deposited on the roof and then affects staircase 1 again, so after 345 s, the visibility of staircase 1 begins to decrease, but does not decrease to less than 10 m.

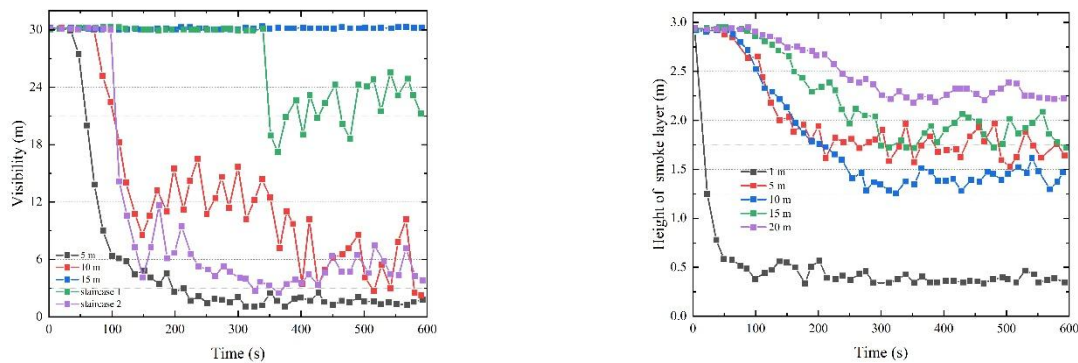


Fig. 4 Visibility at each survey point (left), height of the smoke layer on the second floor (right)

The height of the smoke layer is another important factor affecting the safe escape of personnel during the fire process. Figure 4 (right) shows the change value of the smoke layer height from line 1 to line 5, it can be seen that the height of the smoke layer decreases the fastest at 1 m from the ignition source, and drops to less than 2 m in about 23 s, the smoke layer descends relatively slowly at 5 m and 10 m away from the ignition source, and the height of the smoke layer at 5 m is maintained at more than 2 m most of the time, while the height of the smoke layer decreases to less than 2 m at about 215 s in the range of 10 m from the ignition source, and fluctuates around 1.8 m, which is lower than the safety standard value.

4. Summary

1) The temperature rise rate near the fire source is much higher than that of the location away from the fire source, and the temperature of the place close to the fire source in the middle of the fire exceeds the human safety temperature in about 250 s, because of the good building structure characteristics, the temperature of the rest of the places in the fire is kept below the critical value. Therefore, it is particularly important to stay away from the fire source in the early stage of a fire for evacuation.

2) In the range of 5-10 m from the fire source, the visibility of the floor decreases rapidly after only 48 s of fire and begins to affect the rest of the floors after 114 s, while the height of the smoke layer drops below the safety evaluation standard value in a short period of time near the fire source. Therefore, after a fire occurs, it is necessary to leave the floor in time to ensure the safety of personnel to the greatest extent.

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