Fire Simulation and Safety Evacuation Optimization of mountain ancient building Groups Based on BIM Technology

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Abstract: This study aims to research the law of smoke spread and personnel evacuation when a fire occurs in a mountain ancient building group. First, the BIM model of one mountain ancient building groups in Sichuan Province was established, and the fire spread trend of ancient buildings was analyzed based on fire simulation analysis. After the fire in the ancient buildings, the smoke first develops upward from the fire source and then spreads vertically from high to low. The simulation results show that the flue gas concentration is the most critical factor which affecting the available safe evacuation time. Based on the set fire scene, the personnel evacuation in this scene is simulated by Pathfinder. The results indicate the evacuation emergency channel is narrow and the dense palace area cannot meet the requirements of safe evacuation. By increasing the width of the passageway, it can effectively reduce the personnel density of the congestion point. This study provides a basis for relevant departments to formulate intelligent personnel evacuation plan.

Keywords: ancient buildings; fire simulation; evacuation simulation; BIM

1 INTRODUCTION

Sichuan has a profound historical and cultural heritage. There are many ancient buildings with local characteristics, mostly brick and wood structures. Most of the ancient buildings in Sichuan are based on the environment and integrate the buildings into the natural environment, mostly distributed in the tranquil mountains of the environment. Ancient buildings are generally built on the slope of the terrain. The courtyards are staggered, arranged in groups, and the passages are tortuous. In the event of a fire, it is easy to cause “Burning of the linked camps”, and due to the limited location of the building, the firefighter cannot arrive in time, especially in the tourist rush season, there are many tourists and the evacuation is more complicated. Therefore, it is very important to make a fire emergency evacuation plan.

Scholars have carried out relevant research on the fire spread characteristics of ancient buildings and emergency evacuation. Jiang Shiyong(2013)[1]analyzed the variation of fire-related parameters through simulation for the fire scene of typical ancient temples in Jiuhua Mountain. Shi Lei(2012)[2]took Yuelu Academy as the object,based on the analysis of the fire spread trend, the evacuation models under different fire scenarios were established based on

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Pathfinder, and the influence of the safety exit position on the evacuation efficiency was analyzed.Zhang Lin(2013)[3]took the ancient buildings in the historical and cultural block of Sanfangqixiang as the object, analyzed the fire safety performance, and put forward the fire improvement measures through the evacuation simulation. TIAN Yao(2019)[4], Ren Hailong(2007)[5], Lu Wanli(2011)[6]and other scholars have achieved certain results in the fire spread law and evacuation strategy of ancient buildings. However, most of the research mainly focuses on the analysis of fire spread trend and evacuation of ancient buildings in plain areas, without considering the influence of complex terrain on fire spread trend and evacuation of ancient buildings. Therefore, this paper takes a mountain ancient building group in Sichuan Province as the research object, and analyzes the fire characteristics based on BIM and fire simulation technology. On this basis, Pathfinder is used to simulate the evacuation of ancient buildings in fire scenarios, which provides a basis for relevant departments to formulate emergency plans and fire prevention measures.

2 SUMMARY OF ONE ANCIENT BUILDING GROUPS

2.1 Architectural features

This paper takes an ancient buildings in Mianyang City, Sichuan Province as the research object. The ancient buildings includes 23 buildings in Yuan, Ming and Qing dynasties, mainly brick and wood structure.Including, the temple 1 was built in the early Ming Dynasty, which was a palace-style wooden structure building with a construction area of 300 m^2.According to the investigation and analysis, temple 1 has a high geographical location, and there are four rare varieties of Dangui in front of the palace. The temple 1 is full of incense and fire, and tourists are endless. Once a fire occurs, it will cause serious harm to the safety of ancient buildings and personnel. Therefore, the temple 1 is set as the fire location of the ancient buildings fire simulation.

2.2 Fire facilities

The main structure of the ancient buildings is a beam structure, the wall is made of rammed earth, and the roof is made of clay tiles. These non-combustible materials objectively play a role in fire protection. Fire extinguishers, fire detectors, smoke alarms, fire power supplies, emergency lighting and other equipment were installed in the ancient buildings,and fire hydrant systems and annular fire water channels were installed outside.

3 FIRE SIMULATION

3.1 Establishing BIM model for ancient buildings

At present, ZHENG Guanxia (2022)[7], GUO A-ming (2020)[8], LIU Qian (2020)[9]and other scholars use PyroSim to model and use FDS software to calculate. However, it is very cumbersome to establish 3d model in PyroSim, and the components of ancient buildings are multiplicity and complex, which cannot fully display the various components of ancient buildings，reducing the accuracy and precision of the simulation. Therefore, this paper uses BIM technology to solve the problem of modeling difficulties in FDS, which can not only ensure accuracy, but also improve efficiency. The ancient buildings model established by Revit is shown in Fig.1.

Fig.1 BIM model of ancient buildings

3.2 Selecting the fire scene

According to the incomplete statistics on the fire accidents of ancient buildings, the fire caused by the careless use of fire such as burning incense and burning paper money by tourists is the main cause of fire in ancient buildings(2017)[10].Therefore, this article selects the temple 1 indoor offering table as the fire source. Through field investigation and analysis, the temple is usually open. Therefore, this paper simulates the fire scene for the opening of the temple and the fire source is located in the indoor worship table, and simulates the fire spread and evacuation of the entire ancient buildings when the fire broke out.

3.3 Setting boundary and initial conditions

Create a 1:1 BIM model of ancient buildings, and import the 3D model of ancient buildings established in Revit into the fire simulation software FDS in fbx.format. Considering the timeliness of calculation and the limitations of fire spread, the spread characteristics of fire in mountainous areas were found after several preliminary simulations, and then the red calculation area in Fig.1 was selected for detailed analysis. The model is simplified to establish a grid with a length×width×height of 140m×110m×27m, and the total number of grids is 63000.

4 ANALYSIS OF FIRE SIMULATION RESULTS

4.1 Smoke spread trend analysis

The smoke spread trend at 1m above the ground at different times is calculated as shown in Figure 2. Because the temple 1 is an open scene, when the smoke the height of the door, it will spread outside the temple. At 120s, the smoke filled Temple 1, and part of the smoke spread from the doors and windows to the surroundings. At 165s, the smoke spread completely from the temple 1, and at 202s, the smoke spread to Temple 2, Temple 4 and Temple 3. At 208s, the smoke completely spread to part of Temple 5 and Temple 6, but not to Temple 7.

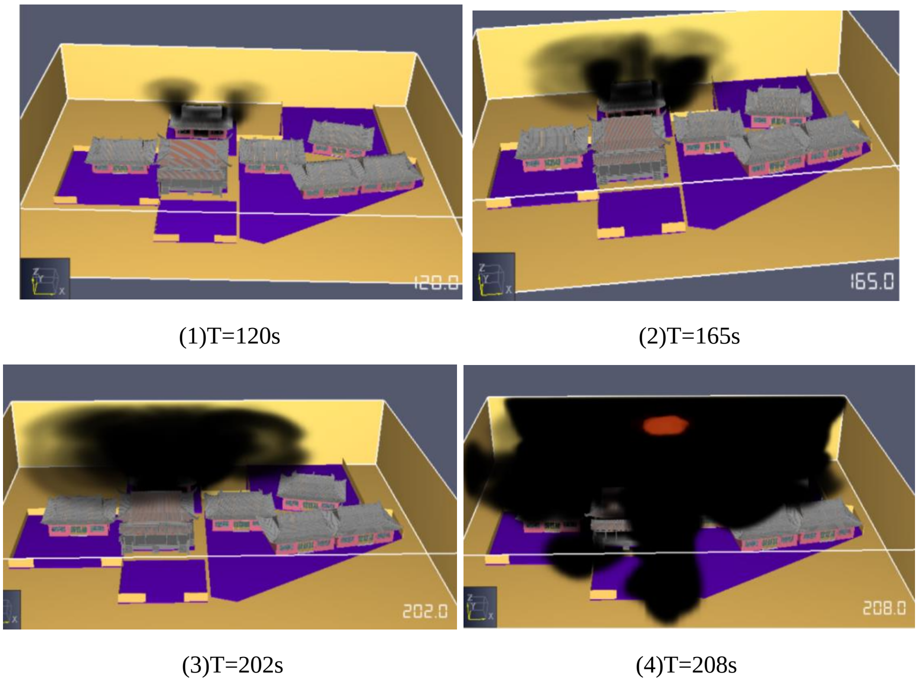
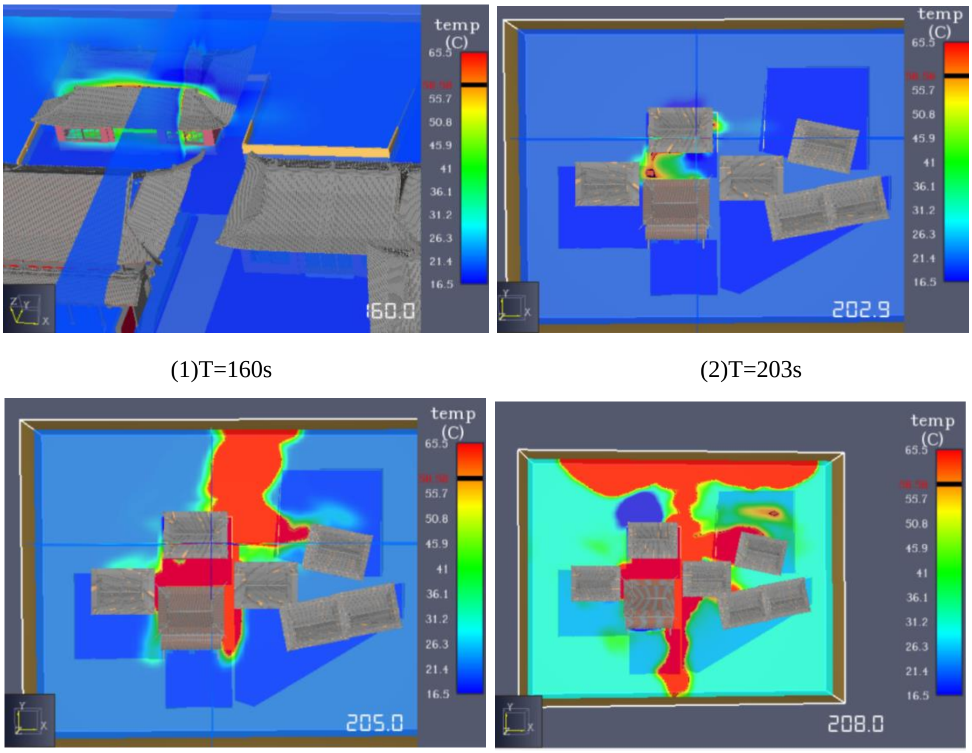


Fig. 2 Smoke spread diagram of ancient buildings

4.2 Temperature analysis

The temperature changes of the ancient buildings at 1m from the ground at different times are calculated as shown in Figure 3.When the fire occurs, the temperature of the fire field in the temple 1 rises rapidly. At 160s, the temperature in the temple 1 is much higher than the human tolerance temperature of 60 ° C and the smoke spreads outward, and the surrounding temperature is also about to reach the critical value. At this time, when personnel should choose the direction of escape, they should avoid the fire area and the dense area of the building. At 203s, the smoke spread to Temple 2 and Temple 4, but the temperature around Temple 3 was still low. At 205s, the smoke mainly spread to the rear of Temple 1, Temple 4 and Temple 2, and gradually spread to Temple 3 and Temple 5.At 208s, the smoke completely spread to the entire ancient buildings, but the temperature in the surrounding areas of Temple 6 and Temple 7 was still low, and people could evacuate to the space in front of Temple 6 and Temple 7.



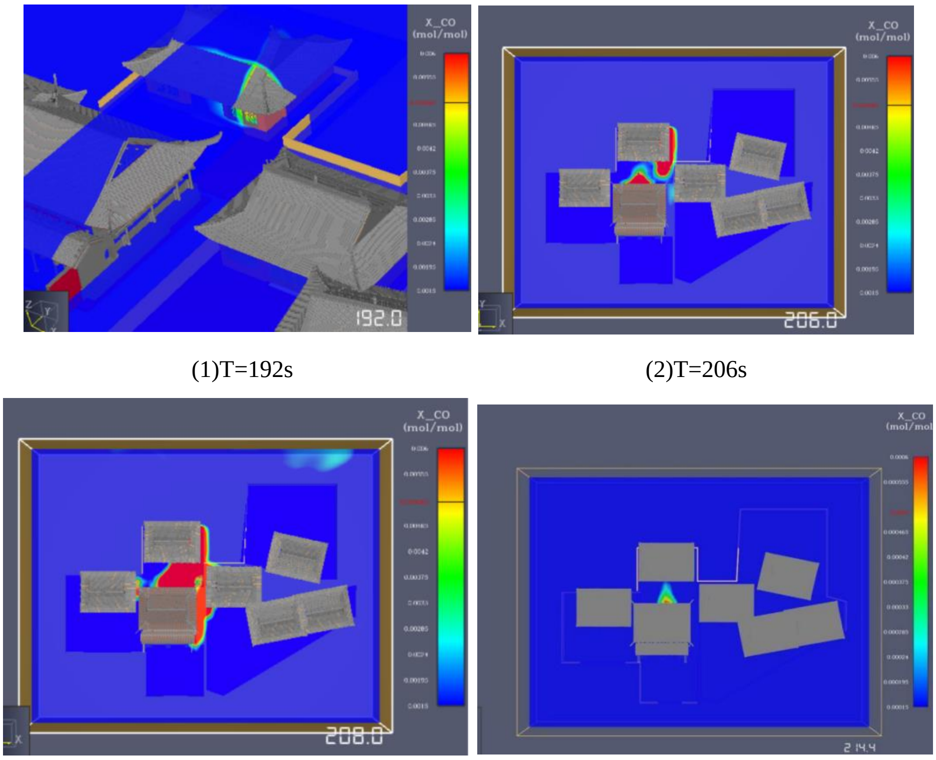
(1)T=160s (2)T=203s

(3)T=205s (4)T=208s

Fig. 3 Temperature slice

4.3 CO volume analysis

According to the literature, fire casualties are mostly caused by CO. When fire occurs, a large amount of CO will be produced. As time goes on, the concentration of CO will become higher and higher. When the volume fraction of CO is 500×10^{-6}, it will hinder personal safety and evacuation. The variation of CO concentration at 1 m from the ground in the calculation area at the same time is shown in figure 4. At 192s, the CO concentration in Temple 1 reaches 500×10^{-6}.At 205s, CO in Temple 1 began to diffuse to Temple 2. At 206s, CO rapidly diffused into Temple 4. At 208s, fire spread to Temple 3, Temple 6 and Temple 7 had no effect, and the evacuation could be evacuated to Temple 6 and Temple 7. CO gradually dispersed at 214s.



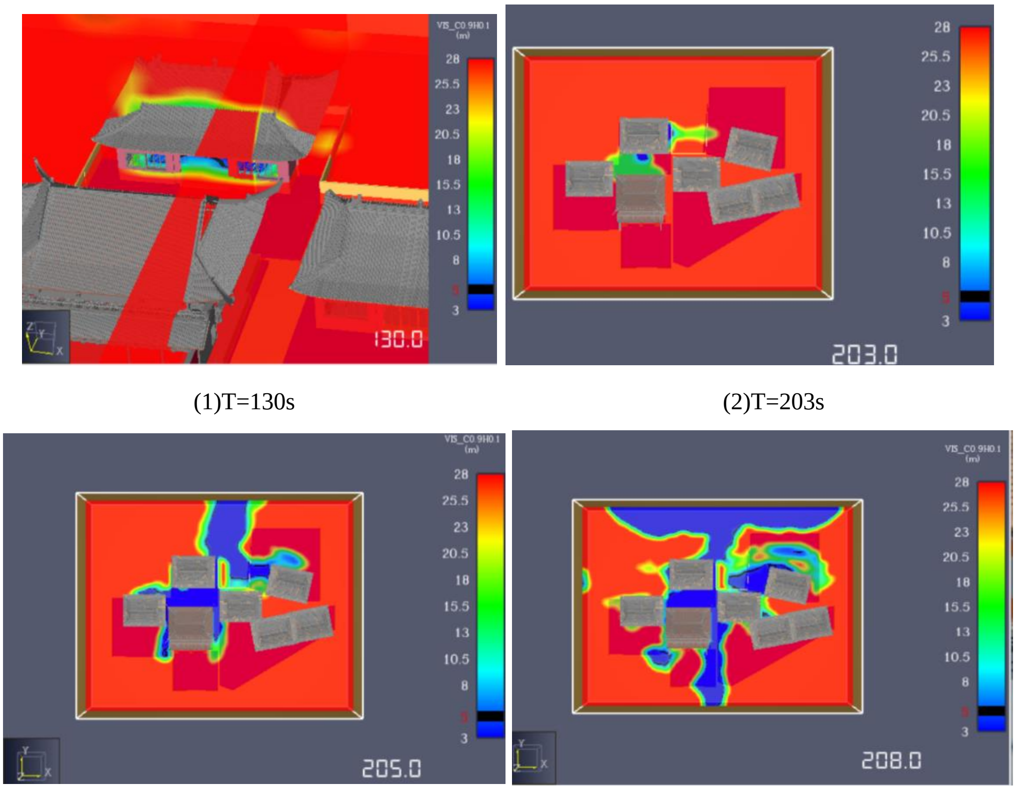
(1)T=192s (2)T=206s

(3)T=208s (4)T=214s

Fig. 4 CO concentration slice

4.4 Visibility analysis

Referring to the " Technical Standard for Smoke Control and Exhaust System of Buildings "(GB51251-2017), the critical visibility of this fire simulation is 5m [11].The changes of visibility at different times are shown in Fig.5.The initial visibility in Temple 1 is 30 m. At 130s, the visibility in Temple 1 decreased to 5 m. As the fire smoke spread to the outside, the visibility of the area near Temple 1 dropped to 5 m at 203s.At 205s, the smoke spread to the buildings around Temple 1, and the visibility of Temple 4, Temple 2, Temple 3 and Temple 5 decreased to 5 m. At 208s, the smoke gradually spread to Temple 6, but the smoke concentration was low, and people could evacuate to Temple 6 and Temple 7.



(1)T=130s (2)T=203s

(3)T=205s (4)T=208s

Fig. 5 Visibility concentration diagram

5 SAFETY EVACUATION SIMULATION

5.1 Personnel evacuation parameter settings

The safety evacuation process of ancient buildings is mainly affected by the flow of people, evacuation conditions, evacuation personnel and other factors(2008)[12].According to the official announcement of the ancient buildings, when the number of visitors exceeds 1400, the control measures of the ancient buildings are implemented, so the total number of evacuation is set to 1400, and the personnel are randomly distributed in each area.Refer to the relevant specifications, set the personnel characteristics in Pathfinder, as shown in Table 1.

Table 1 Personnel characteristics

type	walking speed（m/s）	Shoulder width×back thickness×height	proportion（%）
child	1.00	0.3*0.2*1.3	5
young male	1.55	0.5*0.3*1.7	10

young female	1.45	0.4*0.28*1.6	10
middle-aged male	1.40	0.5*0.3*1.7	25
middle-aged male	1.30	0.4*0.28*1.6	35
elderly	1.10	0.4*0.25*1.6	15

5.2 Safety evacuation standard of criterion

Scholars have shown that(2013)[13] the necessary evacuation time (T_{RSET}) includes three parameters:alarm time (T_1), personnel reaction time (T_2), evacuation time (T_3). The necessary evacuation time (T_{RSET}) can be calculated according to equation (1):

$$T_{RSET}=T_1+T_2+T_3 \tag{1}$$

The alarm time of the common smoke fire detector is about 45s, and the T1 value is 45s. When a fire occurs in ancient buildings, a danger alarm is often issued by means of live broadcast to remind people to evacuate quickly，and the T_2 value is 60s.In general, T_3 is measured by the evacuation simulation software Pathfinder.

The safety evacuation time TASET by the fire simulation software FDS and the necessary evacuation time TRSET by the evacuation simulation software Pathfinder are compared, and finally verify whether TASET > TRSET is true. If it is true, under the given conditions, the danger caused by the fire of ancient buildings can be evacuated to the safe area before reaching the critical value of the dangerous state, otherwise it cannot. It is necessary to improve the fire protection design, complete the safety evacuation system and strengthen the fire protection measures.

5.3 Safety analysis of evacuation simulation

Using the simulation software Pathfinder to establish the evacuation model as shown in Figure 6.In the evacuation simulation process, the average personnel density is 3 people/m2.

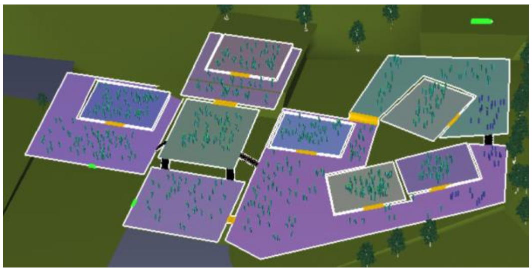


Fig. 5 Evacuation model of ancient buildings

According to the analysis of the safe evacuation time in Table 2, when fire occurs in Temple 1, the $T_{ASET}>T_{RSET}$ in Temple 2, Temple 4, Temple 6 and Temple 7, so the personnel can be safely evacuated.The $T_{ASET}<T_{RSET}$ of Temple 1, Temple 3 and Temple 5, personnel can not be evacuated safely.It is mainly due to the fire in Temple 1, the narrow evacuation channel in Temple 1, and the dense buildings and large population in Temple 3 and Temple 5.Therefore, people cannot be safely evacuated.

Table 2 Comparison table of safety evacuation time of ancient buildings

site	evacuation time (T_3)	T_{RSET}	T_{ASET}	security
Temple1	28	133	130	unsafety
Temple2	69	174	202	safety
Temple3	164	269	202	unsafety
Temple4	66	171	202	safety
Temple5	117	222	205	unsafety
Temple6	164	269	/	safety
Temple7	164	269	/	safety

5.4 The results analysis of safety evacuation after optimization

Using the simulation software Pathfinder to establish the evacuation model as shown in Figure 6.In the evacuation simulation process, the average personnel density is 3 people/m2.

Because the ancient buildings are built into the side of a mountain, the terrain is relatively complex, and in order to maximize the preservation of the original appearance of the ancient buildings so that they are not damaged.Therefore, the scheme of redesigning and increasing the evacuation path is not considered, and the scheme of increasing the width of the channel entrance at the congestion site is adopted.

After optimization, the average personnel density of each time channel port is about 2.55 people / m^2.The evacuation efficiency of this personnel density is higher than that before optimization, which not only ensures the number of evacuees, but also ensures that the evacuation efficiency will not be too crowded. The comparative analysis of evacuation time in each area after optimization is shown in Table 3.

Table 3 Comparative analysis of evacuation time before and after optimization

site	Evacuation time before optimization (s)	Evacuation time for optimization (s)	Shorten time (s)	T_{RSET}	T_{ASET}	security
Temple 1	28	22	6	127	130	safety
Temple 3	164	150	28	241	202	unsafety
Temple 5	117	106	11	211	205	unsafety

After optimization, the congestion phenomenon in the whole evacuation process is obviously reduced, and the evacuation efficiency is greatly improved. The available safe evacuation time of Hall 1 is greater than the necessary time for evacuation. Therefore, when a fire occurs in Temple 1, the personnel can escape smoothly and are in a safe state. However, due to the dense population of Temple 3 and Temple 5, after optimizing the evacuation efficiency, the personnel can not be safely evacuated.

5.5 Fire evacuation advice

Most of the ancient buildings in China are wooden houses. With the loose weathering year by year, the ignition point of wood gradually decreases. The wood of the ancient buildings will burn quickly after encountering the fire source, and it is difficult to evacuate the crowded people in the scenic area. Once a fire occurs in the ancient buildings, it will cause serious casualties and property losses. Therefore, in the technical processing of modern ancient buildings, it is necessary to pay attention to the information and intelligent building management, such as installing intelligent fire monitoring, intelligent power monitoring, water system and lightning protection facilities, and implementing effective monitoring and management of buildings. Secondly, the fire management platform is established and use the Internet of Things information technology to check the potential security risks. The mobile app is connected to the 119 system to realize real-time communication of the information phone. Finally, the mobile app is used to monitor the flow of people, and 3D real-time query of the flow of people in the scenic spot can be used, and focus on the analysis of surrounding information, escape routes, rescue standard operation level, etc., so as to judge the optimal plan for surrounding rescue implementation.

6 CONCLUSION

In this paper, the mountainous ancient buildings in Sichuan Province is taken as the research object. Based on BIM and fire simulation technology, the fire characteristics are analyzed. On this basis, Pathfinder is used to simulate the evacuation of ancient buildings in fire scenarios. The following conclusions can be drawn :

(1)According to the analysis of fire simulation , smoke spread concentration is the most critical factor affecting the available safe evacuation time among the four factors of smoke spread concentration, temperature, CO concentration and visibility. Therefore, the rational use of smoke control measures to reduce the adverse effects of smoke on evacuation can buy more time for escape.

(2)According to the evacuation simulation analysis, when there is a fire in Temple 1, Temple 1, Temple 3 and Temple 5 do not meet the requirements of safe evacuation. It is because the evacuation channel of Temple 1 is narrow, and the ancient buildings of Temple 3 and Temple 5 are dense, but the fire smoke does not spread to Temple 6 and Temple 7. People in Temple 3 and Temple 5 can be evacuated in the direction of Temple 6 and Temple 7.

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