Fire Simulation and Optimal Evacuation Based on BIM Technology

Zhanzeng Li[1(✉)], Yingying Li[2], Yang Ge[3], and Yanmin Wang[3]

[1] China Architectural Design and Research Group, Beijing, China
lizz@cadg.cn

[2] The Architectural Design and Research Institute of HIT, Heilongjiang, Harbin, China

[3] Harbin Institute of Technology, Heilongjiang, Harbin, China
wangyanmin@hit.edu.cn

Abstract. In order to solve the problem of fire inducing and spread process with complex characteristics, this paper proposes a novel approach to realize fire dynamic simulation and evacuation optimization. Focusing on the inducing factors and spread, a fire source heat release rate and combustion model is established based on the technology of BIM and Pyrosim. And the evacuation settings and building environment are further concluded for the accurate dynamic simulation. For the evacuation optimization, the time of different evacuation path corresponding to specific evacuation exit is calculated and compared to achieve the optimal choice of the path in the case of building fire with complex environment.

Keywords: BIM · Pyrosim · Fire combustion · Evacuation optimization

1 Introduction

With the rapid development of social economy, coupled with the breakthrough of building technology, buildings are developing towards high-rise and large-scale, which bring a new challenge to fire safety. In the past five years, there were 142,3000 fires in China, causing 14,2000 casualties [1]. Since the 1990s, the number of building fires in China has accounted for more than 75% of the total number of fires, and the number of deaths and direct property losses caused by them account for 90% and 85% of them, respectively [2]. Building fire has brought great threat to personal safety and property safety, but also brings great challenges in fire safety research. Fire simulation and evacuation analysis are two key problems to be solved.

For the fire simulation, different models of fires have been established and the focuses are key data collection and impact analysis. In [3], a fire diffusion model of students' apartment was established using Pyrosim software to simulate the influence of automatic sprinkler system and windows on the fire layer temperature and smoke height. In [4], a 3D physical model of fire was established, and the spread process of fire smoke was simulated by the software of computational fluid dynamics (FDS). The distribution of high temperature smoke and visibility was studied, and the fire risk time of each fire scene was analyzed. In [5], the law of smoke spread in the process of fire

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development was studied under the fire model in Pyrosim software, and relevant countermeasures and suggestions were proposed for the fire prevention and management of high-rise residential buildings. In [6], the influence of vehicle blockage on smoke flow mode and critical ventilation speed in tunnel fire was studied. In [7], a more practical CFD method was proposed to simulate the air flow in subway tunnels and stations by coupling the heat source in the station with the street level through the entrance and exit. However, the precision of the existing models is not high due to the complex spread characteristics of fire.

For the building emergency evacuation, most researchers focus on the evacuation scenario and efficiency analysis, which provides a theoretical basis for evacuation simulation and optimization. In [8], the evacuation simulation of a university teaching building was carried out based on pathfinder software and the relationship between the number of each floor. And the cumulative number of evacuees and the evacuation time in the daytime and night scenes of the university teaching building was also analyzed. In [9], the software of Pathfinder was used to simulate the emergency evacuation behavior of the crowd. And the room evacuation, floor evacuation and the evacuation of the whole building were also simulated. [10] changes the entrance and exit position and the width of stair flight respectively to simulate the evacuation situation at the entrance and exit of teaching building and the stairs of each floor under different scenes. [11] takes a circular atrium teaching building as the research object to study and analyze the smoke diffusion of the teaching building floor, and to obtain the best evacuation path and escape time of each floor after the fire. [12] studied a model for managing the movement of building occupants in case of fire emergency, which is more effective than the whole building strategy of full-stage building evacuation, partial building evacuation and local refuge. With the development of 5G technology and artificial intelligence, intelligent algorithm is applied in emergency evacuation. In [13], an improved k-medoids algorithm was proposed, which considered the influence of the relationship between individuals and the distance between individuals on the movement of people. In [14], the cellular automata method was used to establish a modified decision-making model under panic state based on field model, and the effect of panic on evacuation behavior was studied. However, the impact of fire environment and key data on evacuation is seldom studied.

Based on the above analysis, taking a school teaching building as an example, this paper proposes an advanced fire simulation and evacuation optimization approach. A fire combustion model combining BIM technology and fire simulation software is established, focusing on the complex spread characteristics of fire and the analysis and optimization of emergency evacuation. It provides suggestions for the fire drill and emergency evacuation of the school teaching building and can be extended to other large buildings.

2 Fire Combustion Modeling

2.1 Fire Parameters Calculation

Temperature and fire spread speed are two important elements in fire simulation [15, 16]. In order to get the temperature change around the fire source for the accurate situation of fire evacuation, we assume that the fire is caused by foam plastic burning substance and occurs in the chair of the teacher's office. And the heat release rate of the fire is exponentially increasing, i.e., there is

$$Q = at^2 \tag{1}$$

where t is the time of fire combustion (s), a is the fire growth coefficient (kw/s^2), Q is the heat release rate (kw).

Considering that the combustible material is foam plastic, the fire source is set as a fast fire. Table 1 gives the growth coefficient of heat release rate of different combustibles in fire and we take the coefficient of rapid fire of the fire growth coefficient, that is, a = 0.04689 kw/s^2. In order to simulate the real fire evacuation, the fire combustion time is first set as 250 s, which is calculated by (1). The heat release rate Q is 2930.63 kw, the integer can be set as 3000 kW. And we set the heat release rate to the combustion heat release rate at the beginning of the fire.

Table 1. Growth coefficient of heat release rate of combustible fire

Fire growth level	Typical combustibles	Fire growth factor (kw/s^2)
Slow fire	Common silicone rubber products	0.00293
Medium speed fire	Cotton and polyester cushion	0.01127
Fast fire	Mail bags, wooden brackets, foam plastics	0.04689
Super fast fire	Pool fire, fast burning furniture, light curtain	0.18781

Furthermore, the fire related parameters are set on Pyrosim software. Considering that the initial ignition source of the teaching building is set on the seat, the combustion area of the fire source is set as 1 m^2. The combustion reaction is a polyurethane combustion reaction. The material is heat conductive solid material and is defined as foam. The materials of other buildings in the space are defined as concrete, gypsum, Pinus ponderosa, steel and tile materials, according to Pyrosim software. The ambient temperature of the room is 20 °C, and the air flow rate is 0 m/s.

Based on the BIM building information model of teaching building, it is imported into Pyrosim software for fire simulation to get the following information concluded as the heat of fire combustion, combustion products, the change of fire temperature field, the gas flow phenomenon in fire space, fire spread and flame spread, the setting of spray device, the installation and monitoring of heat detector and the use conditions of smoke detector key information of sprinkler system start-up, fire extinguishing action and fire combustion change.

2.2 Evacuation Personnel and Environment Setting

Taking a teaching building as an example, two evacuation passageways with different directions are considered according to the relevant design specifications. When the roof height of the public area is lower than 6.0 m, the straight-line distance from all locations in the public area to the nearest evacuation exit should be less than the longest evacuation length of 40.0 m; When the average height in the area is not less than 20.0 m, it is 90.0 m; In other cases, it should not be greater than 60.0 m.

Considering the changes of the number of people in the teaching building during recess, school and after-school, the number of evacuees is set as 1700. Pyrosim software is used to set the evacuation personnel. Differing from the adoption of the traditional software of FDS and Evac, much unnecessary work can be avoided and the evacuation simulation of a five-story teaching building will be carried out.

3 Simulation and Analysis of Fire Combustion

Figure 1 shows the teaching building model established by BIM technology in this paper. The structure and data of building can be got. Figure 2 shows the room distribution on the first floor of the teaching building, and the other floors are similar. And the teachers' lounge is selected as a specific scene to simulate the fire combustion. A smoke sensor is placed at the door of the room to observe the change of smoke concentration and height with time. Here we assume that, the initial growth of the fire is rapid fire, and the fire growth factor is 0.04689. Referring to the technical specification for smoke control and extraction of teaching buildings, the heat release of places without spraying is 6 MW, Q = 230 kw.

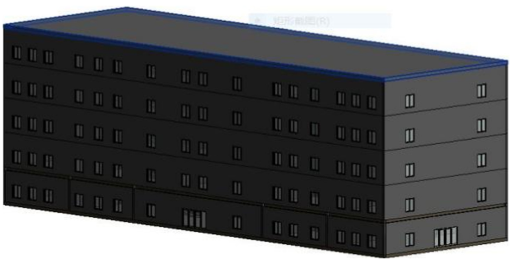


Fig. 1. BIM model of the five-story building

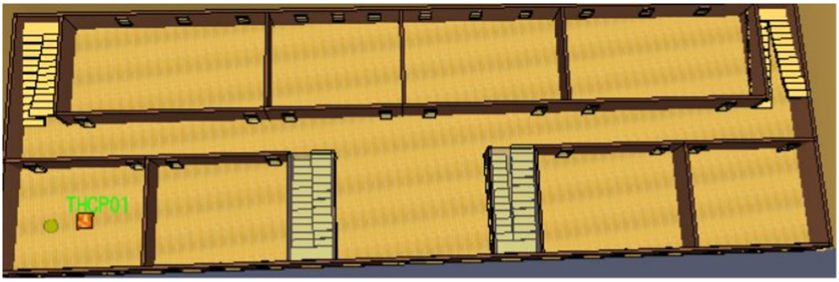
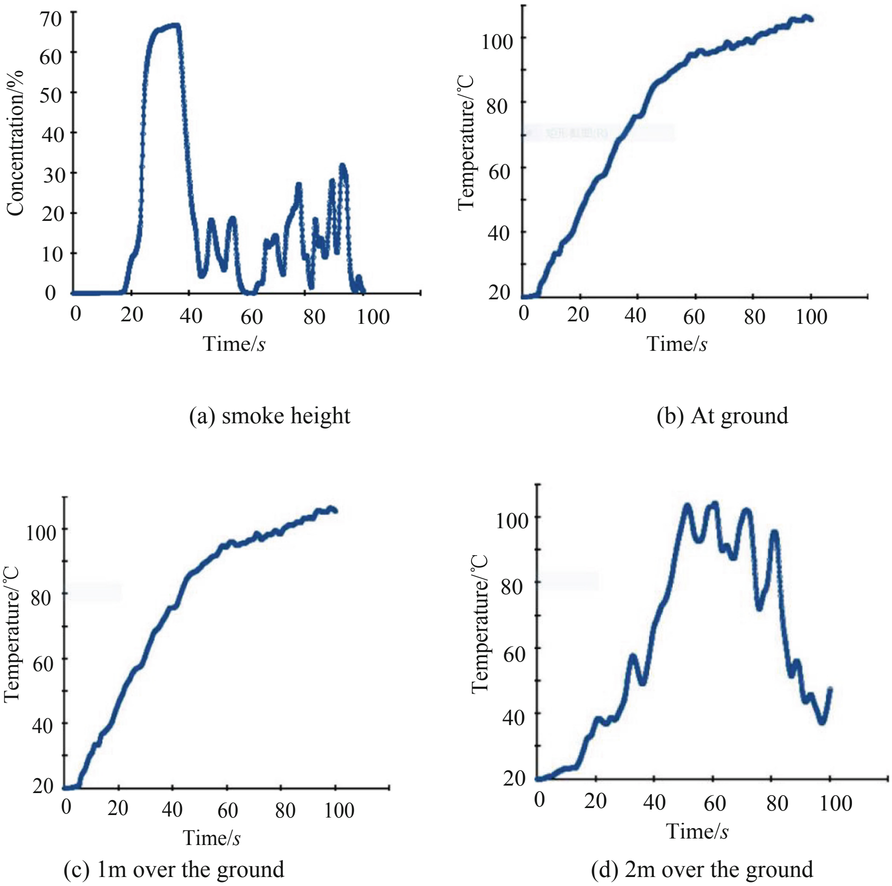


Fig. 2. Room distribution and setting of fire combustion



(a) smoke height

(b) At ground

(c) 1m over the ground

(d) 2m over the ground

Fig. 3. Temperature change in different positions

By combining the software of BIM and Pyrosim, the simulation results concerning the changes of temperature are given in Fig. 3(a)–(d).

In Fig. 3(a), it describes the smoke height change with the time. During 20 s and 40 s, the height of smoke is high to almost 70%, the people have time to run out of the building. After 50 s, the height of smoke is very low to about 30% and it is dangerous for the people in the building. As the fire happens, it spends about 53 s for the room temperature to 100 °C in Fig. 3(b), while in Fig. 3(c), the time for the position of 1 m over the ground is about 71 s. However, it should be noted in Fig. 3(d) that, with the increase of the height, the time for the position of 2 m over the ground is about 76 s, but the temperature vibrates around 100 °C due to the local hot air upward and downward.

4 Analysis and Optimization of Evacuation Path

4.1 Setting of Thermocouples and Ignition Point

In the following, we further investigate the evacuation path when the fire of the building happens. Here we take the Classroom 201 as an example to simulate the ignition point and assume the stairs are the only entrance and exit of the evacuation path. The information of temperature and visibility of smoke is selected for the analysis and optimization of evacuation path. In the second-story BIM model of the building in Fig. 4, we can see that there are four stairs. In order measure the temperature accurately, 29 thermocouples are used, named as THCP01-THCP16, LAYER01-LAYER13.

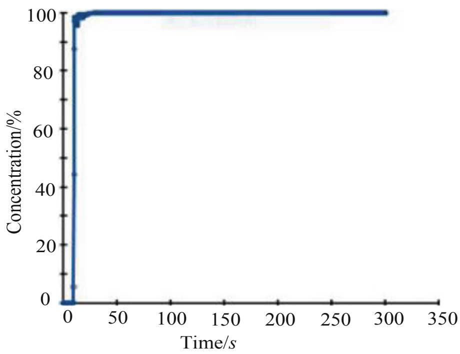
Fig. 4. The setting of thermocouples

For the Classroom 201, its area is 70 m^2 and we set the area of the fire source is 4 m^2. According to the fire load in the building, we assume that the initial growth of the fire is ultra fast fire, the fire growth factor is 0.1878; the heat release of the office without spray is 6 MW, Q = 230 kW, and the time from fire to effective combustion is 178 s.

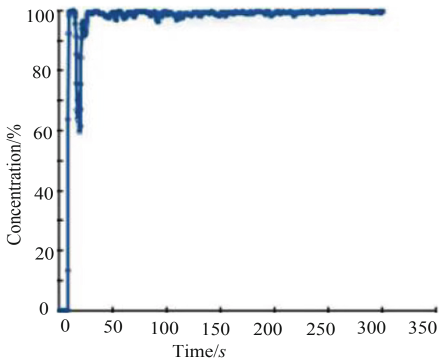
4.2 Simulations

Based on the setting of Fig. 4, we use the software of Pyrosim to simulate the fire combustion concerning the flue gas and these evacuation paths, i.e., left staircase, middle-left staircase, middle-right staircase and right staircase.

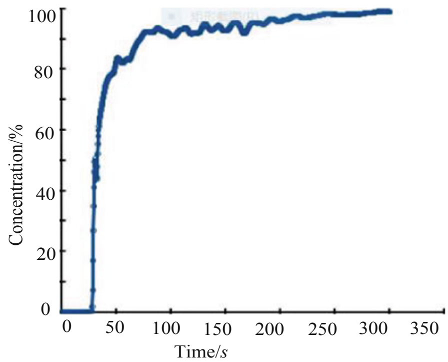
(1) **Spreading process of flue gas**
In order to test the spreading process of flue gas, the thermocouples in Fig. 4 are used. And the height of the judgment point of flue gas sets 1.8 m. The simulations are given in Fig. 5(a)–(d).



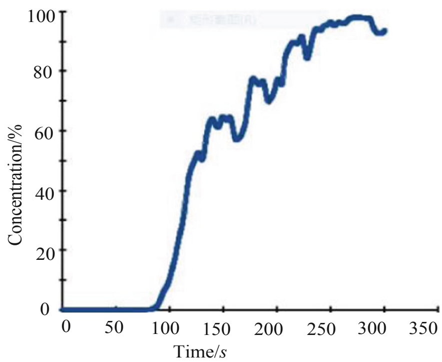
(a) Smoke height around left staircase



(b) Smoke height around middle-left staircase



(c) Smoke height around right staircase



(d) Smoke height around middle-right staircase

Fig. 5. Simulation results of flue gas

Taking 1.8 m as a smoke hazard height determination point, Fig. 5(a)–(d) illustrate the spreading process of the four evacuation paths, i.e., left staircase, middle-left staircase, right staircase and middle-right staircase. The time of smoke reaching the 1.8 m hazard height of the four cases can be got from simulations as 10 s, 25 s, 250 s and 300 s, respectively, which is important for the people to have enough time to escape the building after the fire happens.

(2) **Temperature change around the left staircase**

Focused on the temperature change at left staircase, it is important for the people to escape from this exit. In the following, four cases of the temperature change are considered, i.e., around the ground, 1 m over the ground, 2 m over the ground and 3 m over the ground. As the increase of the height, it is a fact that, the temperature will increase due to the local hot air upward. Meanwhile, as the increase of the time, the temperature oscillation will get slow.

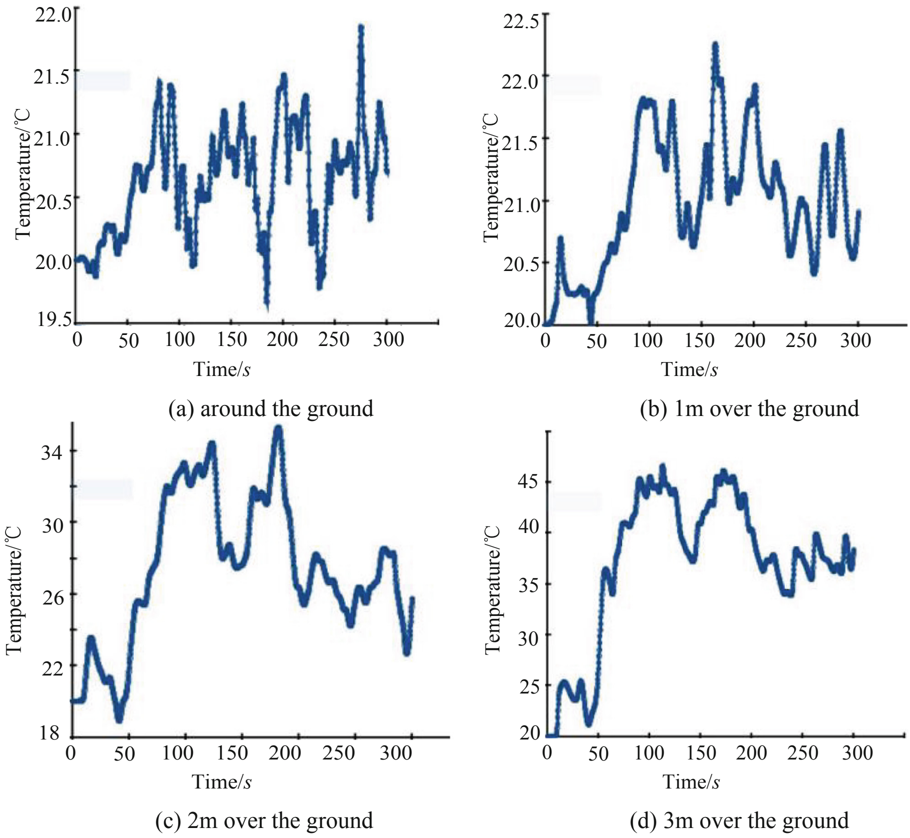
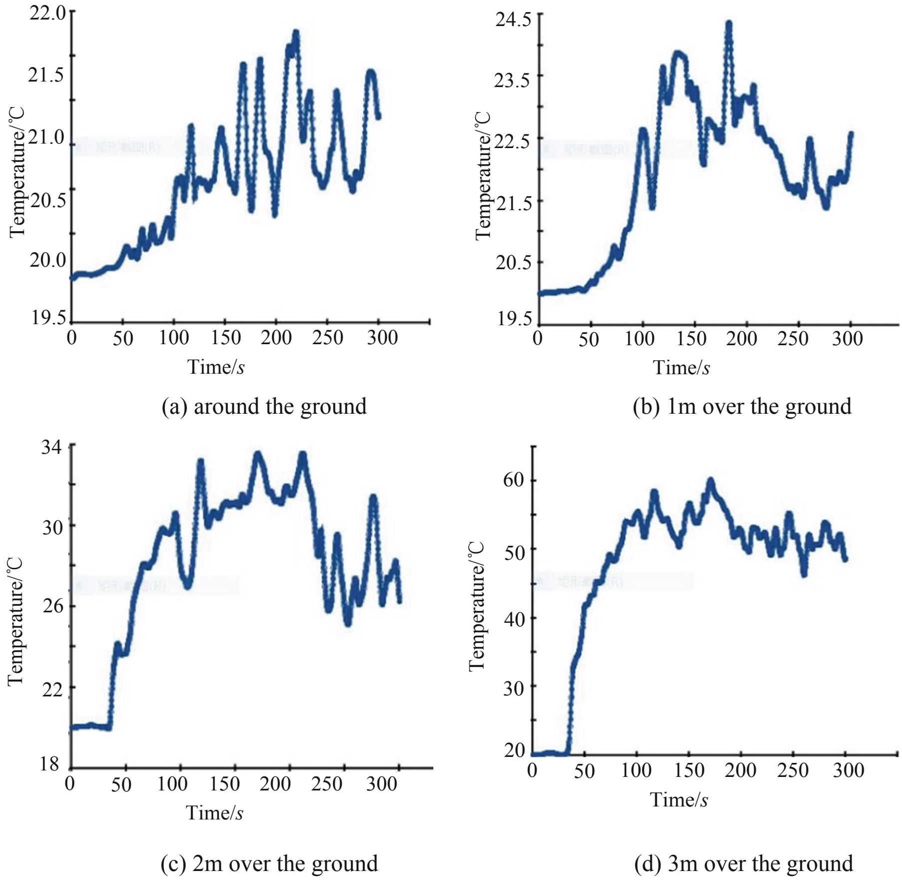


Fig. 6. Temperature change at left staircase

(3) **Temperature change around the middle-left staircase**
Similarly, the temperature change at the middle-left staircase is investigated and given in Fig. 7. Still the four positions around the ground, 1 m over the ground, 2 m over the ground and 3 m over the ground are considered. The same conclusion can be got as that of Fig. 6.
In the following, simulations of the left two cases concerning the temperature changes around the middle-right staircase and the right staircase are given briefly (Figs. 8 and 9).

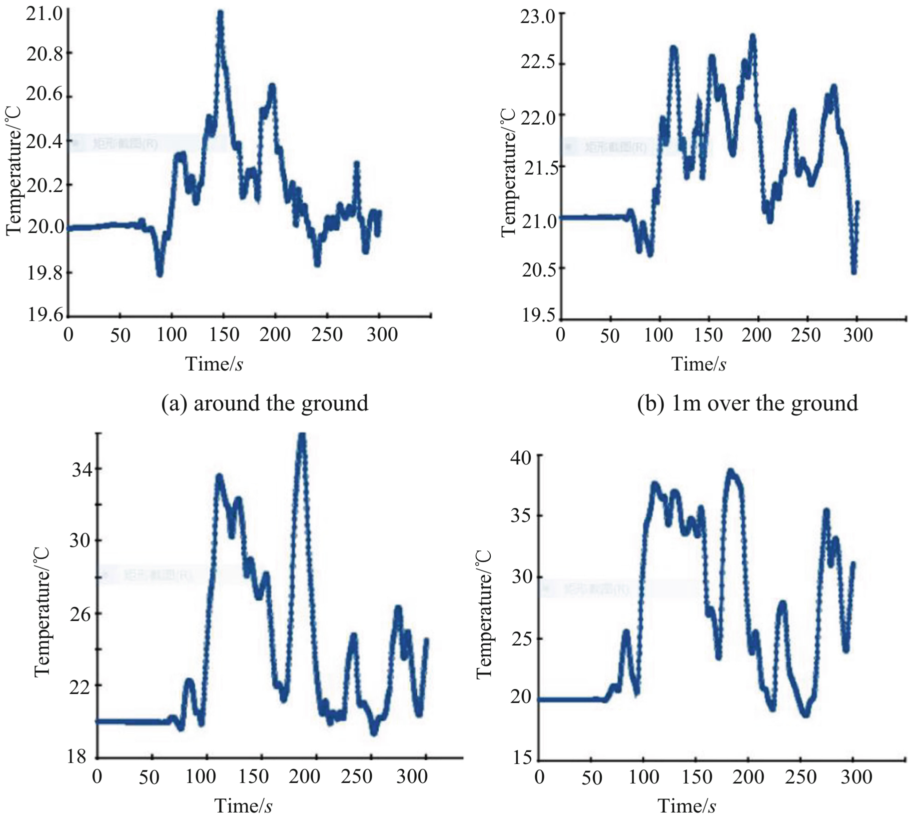


(a) around the ground (b) 1m over the ground

(c) 2m over the ground (d) 3m over the ground

Fig. 7. Temperature change of middle-left staircase

(4) **Temperature change around the middle-right staircase**



(a) around the ground

(b) 1m over the ground

(c) 2m over the ground

(d) 3m over the ground

Fig. 8. Temperature change of middle-right staircase

(5) **Temperature change around the right staircase**

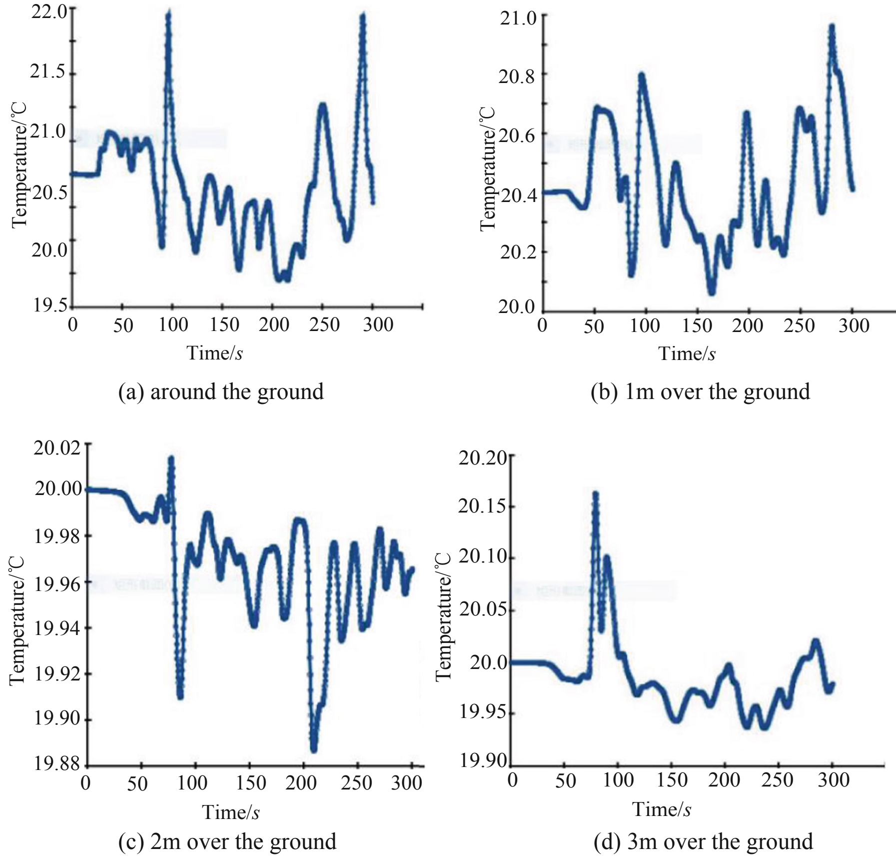


Fig. 9. Temperature change of right staircase

5 Conclusion

In this paper, a novel approach concerning the dynamic simulation of fire combustion and evacuation optimization is proposed based on the technology of BIM and Pyrosim. Taking a five-story teaching building as an example, the temperature and smoke height are two key factors affecting the evacuation of the people in the building. Therefore, the two parameters are investigated around every entrance and exit under typical fire place by setting different thermocouples. It also guides the optimal choice of evacuation paths for the people in the building.

References

1. Hu, Y., Xiao, Q., Wang, H., Li, J.: simulation study on fire scenarios in large space building. J. Beijing Univ. Civil Eng. Archit. **36**(2), 74–79 (2020)
2. Cao, Y.: Fire characteristics and performance-basedfire protection design of large space buildings. Fire Technol. Prod. Inf. **24**(1), 23–26 (2016)
3. Ding, P.: Discussion on comprehensive treatment of dust in cement plant. Hebei Agric. Mach. **12**, 121 (2020)
4. Li, D., Xu, S.: Dust explosion proof and safety control in flour processing plant. Grain Process. **44**(5), 28–30 (2019)
5. Qian, Z., Wang, Y.: IOT technology and application. Acta Electron. Sin. **40**(5), 1023–1029 (2012)
6. Altay, M., Surmen, A.: Effect of the relative positions of vehicular blockage on the smoke flow behavior in a scaled tunnel. Fuel **25**, 694–701 (2019)
7. Fernando, E.C., Greg, B., Rainald, L.: Modeling subway air flow using CFD. Tunn. Undergr. Space Technol. **24**, 20–31 (2014)
8. Ma, H., Ma, Y.: Research on optimization simulation of evacuation on strategy for teaching buildings in colleges and universities. J. North China Inst. Sci. Technol. **17**(3), 105–110 (2020)
9. Fang, X., Yang, Z.: Simulation of high rise building emergency evacuation based on Pathfinder. J. Bohai Univ. Nat. Sci. Ed. **37**(2), 177–183 (2016)
10. Wang, Z., Li, Y.: A study on exit and stairs optimization of teaching buildings based on pathfinder simulation. Saf. Secur. **41**(4), 15–21 (2020)
11. Shen, B., Song, X., Liu, X.: Study on fire smoke flow law and evacuation time of annular teaching building. Shanxi Archit. **47**(1), 1–4 (2021)
12. Groner, N.E.: A decision model for recommending which building occupants should move where during fire emergencies. Fire Saf. J. **80**, 20–29 (2016)
13. Liu, G., Liu, H., Lv, L.: Relationship-integrated crowds simulation. J. Chin. Comput. Syst. **37**(8), 1735–1740 (2016)
14. Chen, C., Tong, Y.: Study on crowd evacuation model under panic state based on cellular automata. J. Saf. Sci. Technol. **15**(6), 12–17 (2019)
15. Bergh, F., Engelbrecht, A.: A study of particle swarm optimization particle trajectories. Inf. Sci. **176**(8), 937–971 (2016)
16. Xiao, Y.: The theoretical basis of CFAST fire model. Fire Tech. Prod. Inf. **25**(3), 90–92 (2018)