Ain Shams Engineering Journal 15 (2024) 102633

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Full Length Article

Emergency evacuation of urban underground commercial street based on BIM approach

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ARTICLE INFO

Keywords:
Urban underground commercial street
Fire dynamic simulator
Personnel evacuation simulation
Evacuation strategy

ABSTRACT

Urbanization has led to increased construction of underground buildings to overcome limited surface space. However, safety concerns in urban underground commercial buildings have become a major issue due to frequent accidents. Ensuring safe evacuation in densely populated underground commercial buildings is crucial. This study focuses on the safe evacuation of an urban underground commercial street A in Fuzhou City. A simulation framework based on Building Information Modelling (BIM) is proposed, integrating the Fire Dynamic Simulator (FDS) and BIM. The framework overcomes limitations in fire dynamic simulators. Using a BIM model, the study analyzes the risk of each fire protection area and selects the most unfavorable area for simulation. PyroSim technology is employed to study the entire fire development process in the underground commercial street under three different fire scenarios. The analysis includes evacuation stair travel time and personnel available safe evacuation time (TASET). By comparing the results, the study optimizes building layout design and identifies factors affecting personnel evacuation efficiency. The simulation outcomes aim to minimize casualties and property losses, contributing to fire safety management in urban underground commercial streets.

1. Introduction

As an effective supplement to urban surface space, underground space has been developed in an all-round way. According to its different functions, it can be divided into different types of underground buildings. At present, the types of underground buildings in China mainly include underground transportation, underground commercial activity places, underground public infrastructure, underground public service facilities, underground material storage, etc. [1]. Underground public service facilities mainly include underground commercial facilities, underground cultural and entertainment facilities, underground sports facilities, etc. The rise of underground commercial street mainly stems from the fact that the traditional business model can no longer meet people's needs for a better life [2]. It is built in the prosperous urban areas, which can not only disperse the passenger flow to a certain extent, but also improve the urban land utilization rate, expand the scope of urban planning, and relieve the urban surface traffic pressure and environmental pressure to a certain extent [3]. The orderly development and utilization of urban underground space is a necessary measure to improve the urban spatial layout and urbanization management pattern, promote the coordination between urban underground space and the overall development of the city, and improve the efficiency of land use [4]. It is of great significance to promote the construction of resilient cities and release ground space to create green ecology [5]. The urban underground commercial street is a special building form formed by digging down from the ground. It is mainly connected with the external space through stairs, smoke vents, lighting atriums, etc. The internal space is crowded, the personnel composition is complex, and there are many combustibles. In addition, poor air circulation and lighting conditions will cause great damage to people's life and property safety in case of fire [6].

The probability of fire in urban underground commercial street is high, which causes serious damage. Based on the study of the relevant laws of smoke diffusion caused by the fire in the urban underground commercial street and the evacuation behavior under the special environment, the practical fire prevention strategy can provide reference for the future fire safety work, and provide a theoretical basis for the fire prevention and escape of the urban underground commercial street. Taking BIM as the platform for modeling and visualizing the simulation results, simulating the fire growth through FDS tools, and accounting the

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https://doi.org/10.1016/j.asej.2024.102633
Received 16 September 2023; Received in revised form 8 November 2023; Accepted 31 December 2023
Available online 16 January 2024

key factors in the evacuation design can provide a reference for the fire design and safety control measures of urban underground commercial streets, which has certain theoretical significance for improving the fire safety design system of domestic urban underground commercial streets. The visualization characteristics of BIM technology can vividly show the whole process of fire smoke diffusion and personnel evacuation in urban underground commercial street. It can replace two-dimensional drawings to provide new ideas for fire safety management training. In case of emergency, it can reduce the impact of building environment and evacuation behavior on evacuation performance, improve evacuation efficiency, and reduce casualties and property losses [7].

The influence of different fire products on personnel evacuation is obtained, and then the safety problems existing in the process of personnel evacuation are analyzed. By improving the internal design layout of the building, it is helpful to provide reference for the design optimization of building fire safety. Through computer simulation experiments, the statistical analysis of the experimental results can provide basic data support for the formulation of the fire protection design code, and provide reference for the formulation of the urban underground space fire protection design code in China.

2. Literature review

2.1. Study on urban underground space fire

In recent years, domestic and foreign researchers have realized the research on the product of urban underground space fire, firefighting equipment system and related influencing factors through building entity, computer simulation and model test, and obtained a lot of research results.

The international research on underground space fire rose earlier, mainly focusing on the spread of smoke, fire risk assessment and the impact of fire on evacuation. Wang et al. [8] analyzed the ventilation and smoke exhaust methods for multi-layer complex subway crossing, and selected typical transfer stations to establish a numerical model. Rozo et al. [9] uses agent-based simulation modeling to design evacuation plans, which considers pedestrian behavior in complex buildings with multiple exit routes. Rie et al. [10] used argon ion laser particle image velocimetry (PIV) technology to realize the visualization of fire source smoke and dust propagation, making it possible to visualize the evaluation of smoke and dust movement characteristics, and then carry out fire safety analysis. Giachetti et al. [11] mainly reduced the solid model by 1/24, and found the best ventilation strategy by studying the upward motion induced by buoyancy and forced convection of mechanical ventilation. The influence of flue gas and the relative position between mechanical exhaust and fire are studied through experiments. It is concluded that the influence of ceiling position on smoke exhaust procedure can be ignored in tunnel compared with fire position. Bjelland et al. [12] pointed out that the effective emergency preparedness of highway tunnels is a problem that needs to be paid attention to in the early design stage, and needs continuous improvement in the operation stage. In order to achieve high-performance emergency preparedness for tunnel fire, the design and operation of tunnels need to be completely changed. Vauquelin, O. and O. Megret [13] reduced the tunnel entity by 1:25 and studied the smoke control caused by fire by longitudinal and transverse ventilation systems.

Wang et al. [14] provided guidance for fire evacuation by analyzing the effects of different evacuation parameters on the evacuation characteristics of irregular underground fires with 50 parameters including the number of evacuations, the minimum group effect, and the time before action. Li et al. [15] proposed a simplified model based on system dynamics for evacuating large crowds from underground complexes in metropolitan areas. It is argued that an initial overpopulation can lead to a rapid decrease in the evacuation capacity of the system, thus significantly delaying the completion of the evacuation process. In addition, the results of the study can provide theoretical support for the development of rules and safety management practices. Jia et al. [16] examined the spread of smoke in an underground shopping mall fire under the composite smoke control mode of smoke barriers and mechanical smoke exhaust systems. The objective was to optimize the choice of smoke exhaust method for underground shopping malls in Fuxin, China. Zou et al. [17] proposed a fire risk assessment method for shopping malls based on quantitative safety checklist and structural entropy weight method and verified the applicability of the evaluation method. The results of the study provide a theoretical basis for further improving the theoretical system of fire risk assessment in shopping centers. By comparing the evacuation time of people, Li et al. [6] analyzed the influence of the number and location of evacuation exits on the evacuation efficiency and proposed relevant design principles. Suggestions are provided for the design of the number and location of exits in underground commercial streets. Wang et al. [18] used an immersive virtual environment to investigate the effect of movement times prior to fire evacuation in individual underground commercial buildings. The distribution of the relevant times was then analyzed by regression. The results show that there are differences in the distribution of occupants' pre-movement times in different underground commercial buildings. A review of the current literature on underground commercial street fires reveals that there are still large gaps in research on the products of fire.

2.2. Application of BIM technology in emergency evacuation research

Scholars in related fields mainly carry out secondary development and utilization of BIM technology and integrate BIM technology with VR technology, GIS technology or other professional technologies for emergency evacuation research. Wang et al. [19] realized the seamless integration between BIM and virtual reality (VR) environment, used BIM to provide comprehensive building information, combined with virtual reality technology (VR) to build an immersive environment with strong adaptability and provide real-time fire evacuation guidance for personnel. Li et al. [20] developed a building information model for computer-aided disaster management system, which interacted through sensors in buildings or sensors carried by rescue teams, greatly promoting the positioning research of indoor personnel. Atyabi and Rajabifard [21] used BIM and GIS technology to integrate the internal environment and network to find the best path during emergency evacuation. Sun and Turken [22] developed a simulation framework based on BIM, combined with fire dynamic simulator (FDS) and agent-based modeling (ABM), to achieve evacuation performance simulation of different building layout scenarios. Wang et al. [23] combined BIM with fire dynamics simulator to improve fire safety management practices, including evacuation assessment, exit planning, fire safety education and fire equipment maintenance. Ma et al. [24] built a fire emergency management system (FEMS) based on building information modeling (BIM) platform, which considers the behavior decisions of building users (such as escape, waiting for rescue and firefighting).Choi et al. [25] developed an automatic inspection and evaluation mechanism for BIM data to check the compliance of evacuation through automatic evacuation rules, which is conducive to evaluating the building's disaster prevention system and exit routes. Teo et al. [26] proposed a multi-functional geometric network model based on BIM, which integrates building information model (BIM) and geographic information system (GIS) to achieve data interoperability. Through integrated indoor and outdoor information, indoor escape routes can be reasonably planned in a short time to improve the emergency evacuation capability under indoor environment. Wehbe and Shahrour [27] proposed a fire evacuation system combining building information model (BIM) and intelligent technology, which is conducive to early fire detection and determining the best evacuation path. Cheng et al. [28] developed a simulation model for offshore oil and gas platforms to evaluate different evacuation plans by integrating building information model (BIM) technology and agent-based model (ABM) to improve evacuation performance. Marzouk et al. [29] proposed to plan the labor evacuation at the construction site by selecting appropriate construction method alternatives in combination with building information model (BIM) and computer simulation, considering the three standards of total construction cost, execution time and labor evacuation time. Hong et al. [30] investigated the effectiveness of BIM based human behavior simulation in promoting accessibility and fire evacuation performance in the analysis examination of architectural students, aiming to better respond to the emergency situations faced in reality by using human behavior simulation.

2.3. Technology roadmap

To sum up, many scholars have integrated BIM technology with other advanced professional technologies or professional applications, and applied it to the study of evacuation process simulation and evacuation behavior characteristics in case of fire and other emergencies. However, the specific impact of fire products on the evacuation process has not been considered in the research process.

On the basis of research at home and abroad, aiming at the problems such as casualties and property losses caused by frequent fire accidents in urban underground commercial streets, the paper realizes the integrated application of BIM technology and PyroSim. In consideration of the fire products, this paper analyzes the problem of safe evacuation of people in urban underground commercial streets under the most unfavorable building fire environment, and proposes effective fire safety evacuation management strategies, which can provide practical reference for safe evacuation of urban underground commercial streets and improve the ability of urban underground public space to prevent and mitigate disasters.

Analyze the flow law of smoke under the fire scenario of urban underground commercial street, carry out research on personnel safety evacuation, propose targeted safety countermeasures and suggestions, achieve effective prevention and management of fire safety in urban underground commercial street, and reduce casualties and property losses in emergency. Building the model of urban underground commercial street based on BIM, this paper first introduces the concept and characteristics of BIM, then analyzes the limitations of fire and safe evacuation modeling, as well as the feasibility and advantages of BIM in safe evacuation. Finally, taking an underground commercial street of A city in Fuzhou as an example, this paper constructs the BIM model of urban underground commercial street.

The numerical simulation of urban underground commercial street fire based on BIM, the simulation scenario is set by selecting the simulation area, fire scenario setting, site creation and risk factor judgment, and the PyroSim fire evacuation software is used to study and analyze the factors that affect the evacuation of people in the fire products. According to the characteristics of urban underground commercial street, this paper first uses Revit to model the geometric figures of buildings, and then adds non geometric figures such as building materials to the model elements. Import the BIM model into PyroSim software in the format of "FBX" to analyze the smoke movement law, temperature field distribution, smoke layer height, CO concentration and visibility of the fire, and finally obtain the available safe evacuation time (T_{ASET}).

The technical route of this study is shown in Fig. 1:

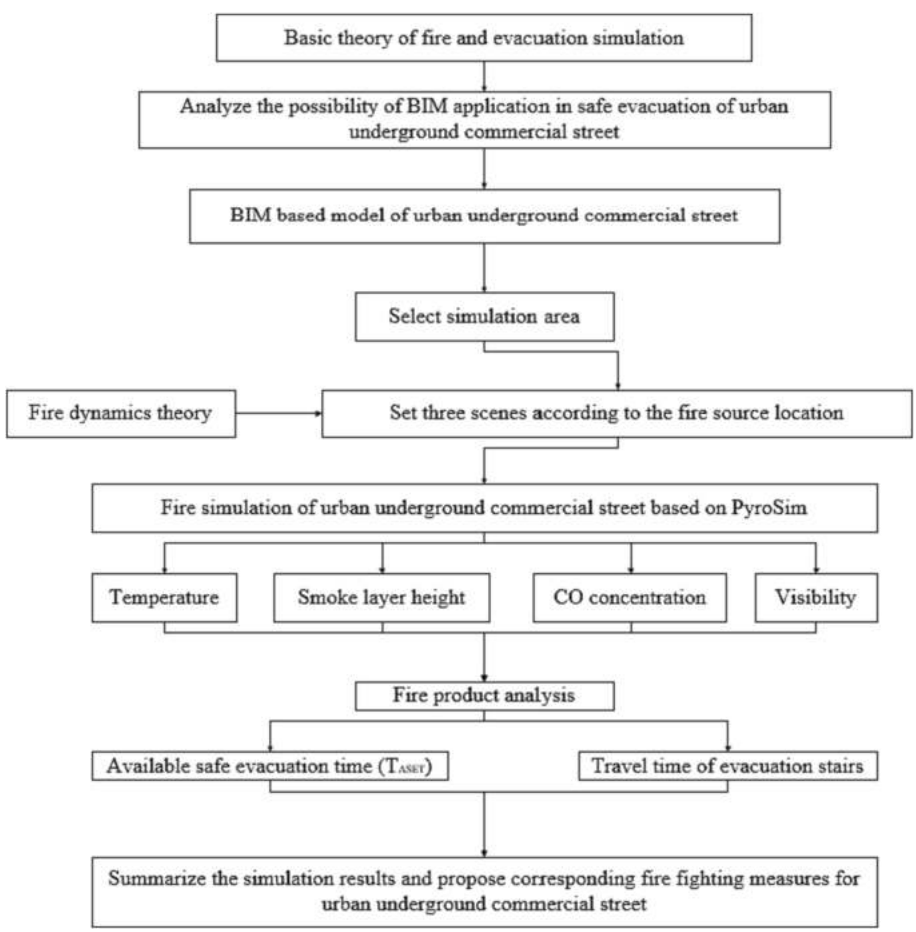


Fig. 1. Technical roadmap.

3. Numerical simulation of urban underground commercial street fire based on BIM

3.1. BIM based modeling of urban underground commercial street

3.1.1. Overview of urban underground commercial street project

Taking an underground commercial street in A city of Fuzhou as an example, the seismic resistance and crack resistance of this project is 8 degrees, the regional roughness is C, and the fire resistance rating is I. This commercial street is located in the center of the city with the largest pedestrian flow. It is a complex composed of one underground floor and three above ground floors. The paper mainly studies the underground part, so the above ground buildings will not be described. The available evacuation area of the urban underground commercial street is 5957.38 m^2, which is a relatively large commercial street, mainly composed of shops, escape routes and equipment control rooms. Fire hydrants are arranged in corridors, halls and equipment rooms with obvious marks. The maximum spacing between fire hydrants is less than 25 m, meeting the Code for Fire Protection Design of Buildings. This commercial street is equipped with super fireproof rolling shutter doors, which can receive the signal from the alarm system in time when a fire occurs and automatically close the rolling shutter doors by using the self-weight to prevent the smoke from spreading to other areas, giving enough evacuation time for people in other areas. Evacuation passages can be divided into stairs, escalators and (fire) elevators, with obvious exit guidance signs. The staircases are smoke proof, with two fire doors and smoke control facilities. Compared with the enclosed staircases, the staircases are more protected against fire and smoke. The fire doors from the evacuation corridor to the antechamber and from the antechamber to the stairwell shall be Class B and open to the evacuation direction, as shown in Fig. 2. The commercial street is also equipped with mechanical smoke control system, emergency lighting system, automatic alarm system, broadcasting and other communication facilities to ensure that people can evacuate in sufficient time.

See Table 1 for fire resistance limit (h) and combustion performance of building components of urban underground commercial street (see Fig. 3.).

According to the properties of the items sold, the shops can be roughly divided into: bookstores, catering stores, clothing stores, electrical appliances stores, etc. Although the building materials are noncombustible, most of the goods in the shops are combustible, so once a fire occurs, the fire spreads rapidly. Through understanding the building structure, plane layout and surrounding environment of the city's underground commercial street, we can divide the building into four fire zones based on the fire shutter doors. Use Revit Architecture to build the main building of urban underground commercial street.

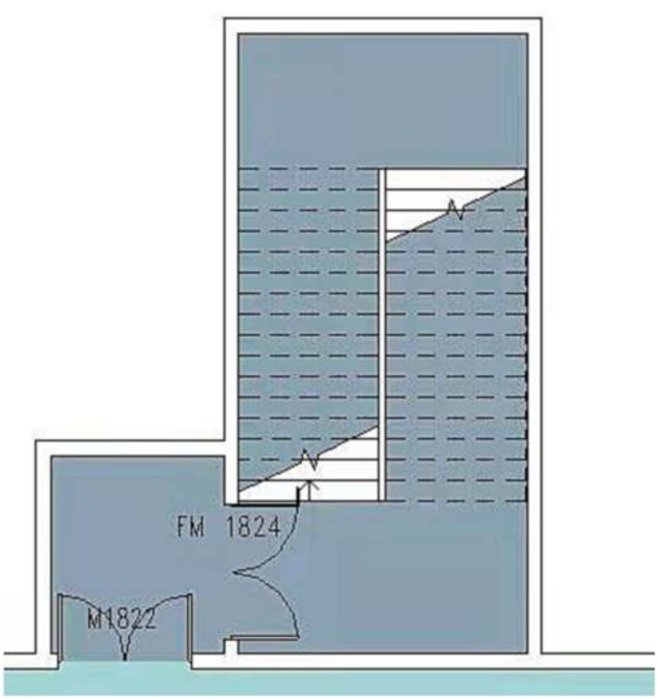


Fig. 2. Schematic diagram of smoke proof staircase.

Table 1
Fire resistance limit and combustion performance of building components.

Position	Combustion performance	Fire resistance limit (h) (Fire resistance rating is Class I)	Fire resistance limit (h) (Fire resistance rating is Class II)
Firewall	Incombustible	3.00	3.00
Room partition	Incombustible	0.75	0.50
Load-bearing wall	Incombustible	3.00	2.50
Staircase and front room walls	Incombustible	2.00	2.00
Column	Incombustible	3.00	2.50
Beam	Incombustible	2.00	1.50
Floor	Incombustible	1.50	1.00
Escape stairs	Incombustible	1.50	1.00
Suspended ceiling	Incombustibility (Class I) Flammability (Class II)	0.25	0.25

Revit is a commonly used BIM software. A building model is created in Revit and the building elements are geometrically modeled and the building model is imported into PyroSim.PyroSim will read the model geometry, material properties, and other relevant information. In PyroSim, you can define fire sources, smoke vents, boundary conditions, and other simulation parameters. After completing the simulation, the results can be viewed and analyzed using PyroSim's built-in analysis tools.

3.1.2. Model building steps

In the drawing part of the main building, the paper draws in the order of "columns, beams, walls, plates, doors and windows, stairs" and other components. The beam component is above the column component, so first draw the column component to prevent it from being obscured by beams, walls and other components. Wall components can be drawn based on the boundary of columns and beams. The slab can be drawn based on the boundary of the wall. The drawing of doors and windows needs to be behind the wall, because the host to which the doors and windows are attached is a wall. If the wall does not exist, the doors and windows do not exist.

In order to standardize the operation process in the evacuation simulation, various types of "rooms" in the urban underground commercial street are classified and simplified into shops, corridors, stairs and others. In case of fire, the escalator and elevator will stop using. For safety reasons, people can only evacuate to the ground through the stairs, so there is no escalator and elevator. Smoke exhaust shaft, oil smoke shaft, electric shaft and equipment control room are all set as "others", which are used as "obstacles" during evacuation. According to the above steps, build models of each fire zone, as shown in Fig. 4.

Taking an underground commercial street of A city in Fuzhou as an example, the BIM model of urban underground commercial street is established to realize the information interaction between BIM modeling software, fire simulation software and evacuation software.

3.1.3. FDS governing equation

PyroSim is a proprietary computational Fluid Dynamics (CFD) software based on large eddy simulation. The basic equations required to build the simulation are as follows:

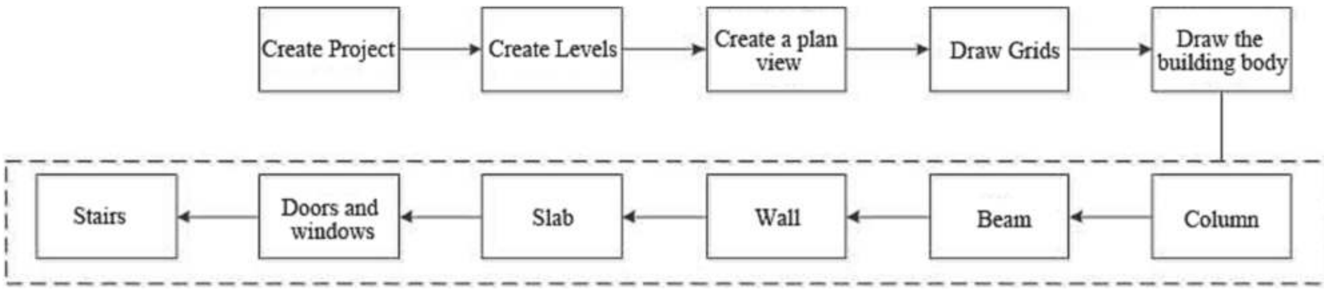


Fig. 3. Schematic diagram of model construction steps in revit.

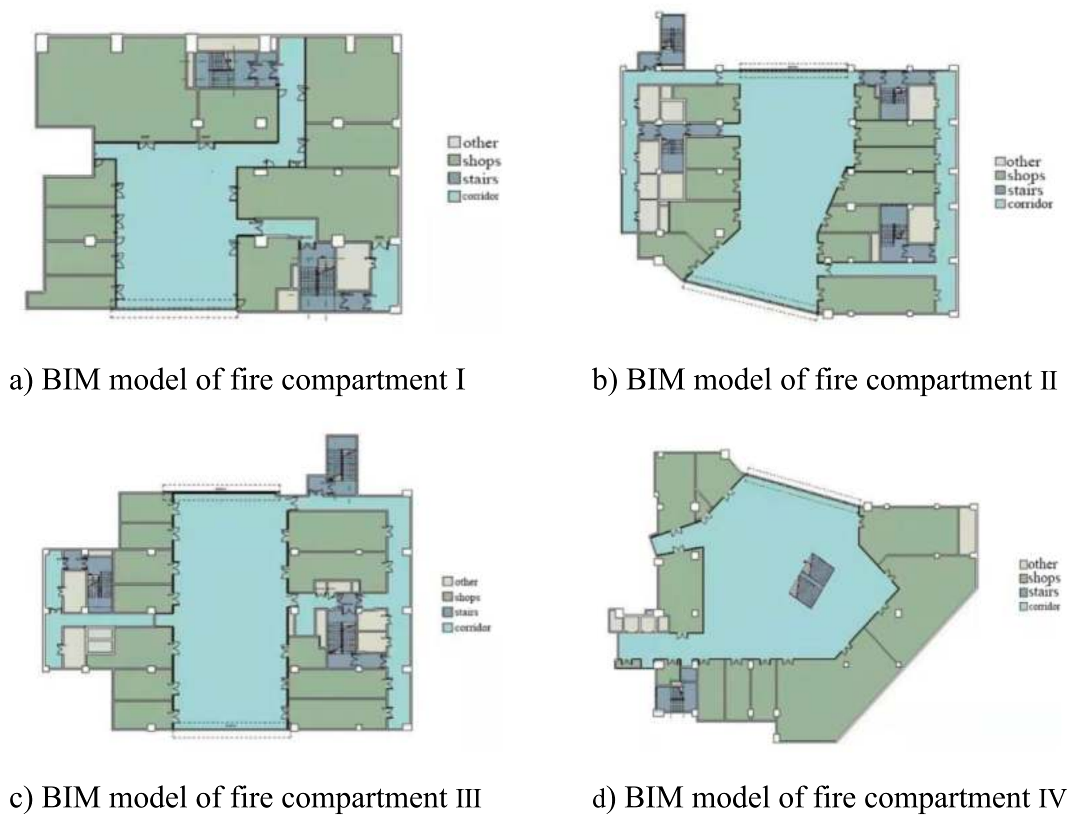


Fig. 4. BIM model of fire compartment.

Mass conservation:

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

Momentum conservation:

$$\rho\left(\frac{\partial u}{\partial t} + \frac{1}{2}\nabla|u|^2\right) + \nabla \rho - \rho g = f_b + \nabla \bullet \tau_{ij} \quad (2)$$

Energy conservation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \bullet (\rho h u) = \frac{\partial p}{\partial t} + u \bullet \nabla p - \nabla q_r + \nabla \bullet (k \nabla T) + \sum_i \nabla (h_i \rho D_i \nabla Y_i) \quad (3)$$

Component conservation:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \bullet (\rho Y_i u) = \nabla (\rho D_i \nabla Y_i) + m_i^{'''} \quad (4)$$

Where:

ρ—Density, mass per unit volume (kg/m^3) ;
t—Time (s) ;
u—Velocity vector (m/s) ;
g—Gravitational acceleration (m/s^2) ;
f_b—External force vector (N) ;
τ_{ij}—Viscous stress tensor (N) ;
p—Pressure (Pa) ;
Y_i—Concentration of the i th component;
D_i—Diffusion coefficient of the i th component (m^2/s) ;
h—Enthalpy (J/mol) ;
q_r—Radiant heat flow (W/m^2) ;
T—Temperature (K) ;
$m_i^{'''}$—The rate of mass production of the i th component in unit space.

3.2. *Fire simulation scenario setting of urban underground commercial street*

The BIM model built is combined with PyroSim in the FDS tool to avoid the tedious steps of setting X, Y, Z direction parameters multiple times in FDS. The BIM model can be imported into the fire simulation software by converting the file format, which can realize the information transfer between BIM and FDS [31]. With the powerful function of BIM software, the limitation of fire simulation software in simulation modeling is solved, and the accuracy of modeling and simulation results is improved.

3.2.1. Simulation area selection

The safety evacuation time of urban underground commercial street fire needs to be calculated by computer simulation. The building area of the underground commercial street in A city of Fuzhou is large. In order to facilitate the calculation, the most unfavorable result is obtained by analyzing the four fire prevention areas.

The statistical area of shops, corridors and stairs in fire compartments I–IV is shown in Table 2. Fire compartment I has two evacuation staircases directly reaching the ground, and the total area of the evacuation area is 1206.52 m^2. Fire compartment II is equipped with three evacuation stairs, with a total area of 1369.34 m^2. Fire compartment III is equipped with four evacuation stairs, with a total area of 1533.82 m^2. The fire compartment IV is provided with four evacuation stairs, and the total area of the evacuation area is 1847.70 m^2. According to the Code for Fire Protection Design of Buildings, the conversion coefficient of the number of people evacuated from the urban underground commercial street is set as 0.85 people/m^2, the conversion value of the area should not be less than 70 %, and the index of the evacuation width per 100 people is 0.75 m/100 people. The following calculations are made for each fire protection area according to Formula (5), Formula (6) and Formula (7). By knowing the conversion coefficient of the number of evacuees and the conversion value of the area, the number of evacuees in the four fire zones is calculated as 718, 815, 913 and 1099 respectively. The ratio of evacuation routes in each area to the total area is 1.29, 2.09, 2.08 and 1.62 respectively. According to the calculation, the evacuation width of each area is 5.38 m, 6.11 m, 6.84 m and 8.25 m respectively. Through the above comprehensive analysis, fire compartment I can be set as an unfavorable area, and further fire simulation and evacuation simulation can be conducted for this area.

$$N_i = S_i \times K \times D \quad (5)$$

$$P_i = \frac{S^*}{S_i} \quad (6)$$

$$W_i = \frac{N_i \times E}{100} \quad (7)$$

Where:

N_i—Evacuation number in fire protection area i (person);

S_i—Area of fire protection i area (m^2);

K—Area reduction factor;

D—Conversion coefficient of evacuation number;

S^*—Evacuation passage area (m^2);

P_i—Ratio of evacuation passage in fire protection area i to the total area of the area;

W_i—Evacuation width of fire protection area i (m);

E—Evacuation width index for 100 people (m/100 people).

3.2.2. Fire scenario setting

According to the structure of urban underground commercial street, distribution of evacuation exits and personnel information, the location with the greatest fire risk is selected as the fire source location. According to the simulation area analysis, fire zone I is the most unfavorable area, so the fire source is set in fire zone I. The layout plan of fire compartment I is shown in Fig. 5.

Based on the analysis of the design plan of fire compartment I combined with the actual investigation, it is found that the Escape stair 2 is connected with two passages and consists of two single running stairs. One end can be used for direct evacuation of shop staff on both sides of the hall corridor, and the other end can be evacuated through the back door of Shop 9. In order to facilitate the follow-up study of evacuation simulation, the right staircase in the area of evacuation staircase is marked as Escape stair 2, and the left staircase is marked as Escape stair 1. If the fire source is set at the location of Shop 9, the smoke will spread rapidly in all directions. This location affects the safe evacuation of people from Escape stair 2, greatly blocks the access to Escape stair 2, and makes it difficult for people to evacuate and rescue. Therefore, the fire source is set in Shop 9, marked as Point A.

Escape stair 1 of fire compartment I is a double running staircase, which is one of the main evacuation exits. Once it cannot be used normally, people will quickly gather at the two evacuation stairs, which may cause congestion and casualties. Therefore, set the fire source in Shop 2, close to Escape stair 1, and mark it as Point B.

When the hall corridor is equipped with movable platforms or temporary shops, if there is a fire in the hall corridor, the shops on both sides of the corridor and the people on the corridor must react quickly according to their own positions and the surrounding environment, and choose the best evacuation exit. Therefore, when a fire occurs in the corridor, it will cause psychological pressure to more people around, and adversely affect the evacuation effect of the evacuation stairs to varying degrees [32]. To some extent, the fire will prevent some people from choosing Escape stair 2, which is not conducive to rapid escape. Therefore, when the fire source is set in the hall corridor, an unfavorable scene is formed, which is marked as point C.

Fire scenarios are set according to the principle of adverse evacuation. It can be seen from the above analysis that the simulation area and fire source location have been selected. In order to reduce the harm caused by fire, sprinkler system and mechanical smoke control and exhaust system are installed inside the urban underground commercial street. The fire situation of urban underground commercial street belongs to the extended fire model, and the heat release rate changes with

Table 2
Area of each fire protection area.

Region	Shop/m^2	Corridor /m^2	Stairs /m^2	Total /m^2
Fire compartment I	738.14	387.89	80.49	1206.52
Fire compartment II	510.41	740.4	118.53	1369.34
Fire compartment III	572.83	797.92	163.07	1533.82
Fire compartment IV	951.82	826.52	69.36	1847.70

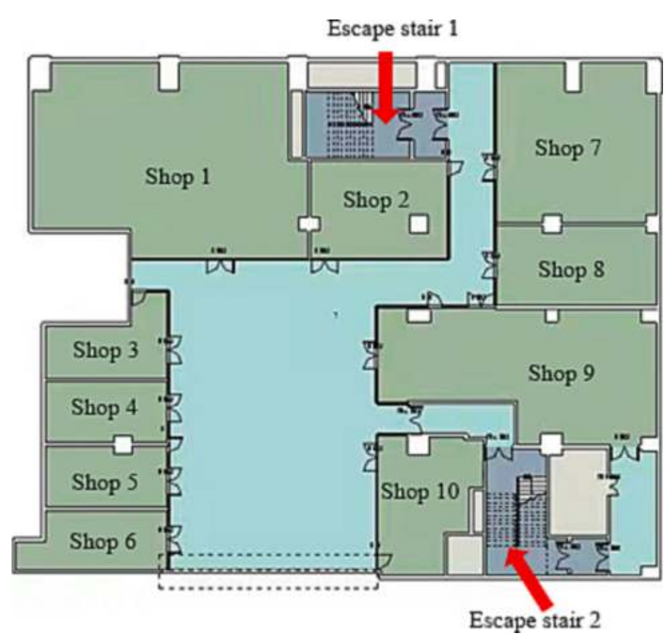


Fig. 5. Layout plan of fire compartment I.

time in an unsteady state. The spray system can control the fire well by reducing the maximum heat release rate, reduce the harm of smoke to human body, and gain more mobile time for personnel evacuation [33]. In order to ensure the worst simulation results, the fire scenario settings should assume that the sprinkler system and mechanical smoke control and extraction system are invalid. After the above analysis of the simulation area, fire source point and firefighting equipment, three scenarios are set, as shown in Table 3, and the scene comparison layout is shown in Fig. 6.

3.2.3. Creating fields

Import the built model in BIM into PyroSim in a three-dimensional state.

(1) Gridding

When PyroSim is used to study the smoke situation of urban underground commercial street in case of fire, grid division is required. PyroSim divides the model into element grids, and the part beyond the grid will not be calculated. In order to ensure the accuracy of the simulation results, it is necessary to divide the mesh reasonably according to the size of the model. If the grid is too large, the simulation process cannot be reflected in detail, and the results lack authenticity. If the grid division is too small, it will not only consume simulation time, but also need to consider whether the computer performance can support the whole simulation process, and whether there will be a “stuck” phenomenon. The building area of fire compartment I of urban underground commercial street is 1251.24 m^2, and the length and width of urban underground commercial street are about 43 m and 34 m respectively. In order to simulate the best accuracy, the grid size is set to 0.5 m $\times$ 0.5 m $\times$ 0.5 m.

(2) Determination of fire source and location

The fire source location has been determined as point A, point B and point C in the previous section. The fire source size is related to the fire growth type and heat release rate of the urban underground commercial street. After creating the object surface, set the heat release rate of different surfaces.

(3) Set detector

T_{ASET} can be determined according to the thermal radiation, temperature, toxic gas concentration and visibility of the smoke. Accordingly, the radiation intensity is set as 3 kw/m^2, and CO concentration detector, temperature detector and visibility detector are set 1.5 m above the ground.

(4) T_{ASET}

According to the calculation of each index of the influence factors of smoke on human body, the available escape time of urban underground commercial street personnel is obtained.

3.2.4. Determination of risk factors

According to the index analysis of the main obstacles affecting the evacuation of people, when the flue gas height is 1.5 m, the flue gas temperature cannot exceed 60 ℃, otherwise the human body’s tolerance

Table 3
Fire Scenario Setting.

Scenario	Region	Position
Scenario I	Fire protection area I	Point A (in shop 9)
ScenarioII	Fire protection area I	Point B (in shop 2, close to Escape stair 1)
ScenarioIII	Fire protection area I	Point C (hall corridor center)

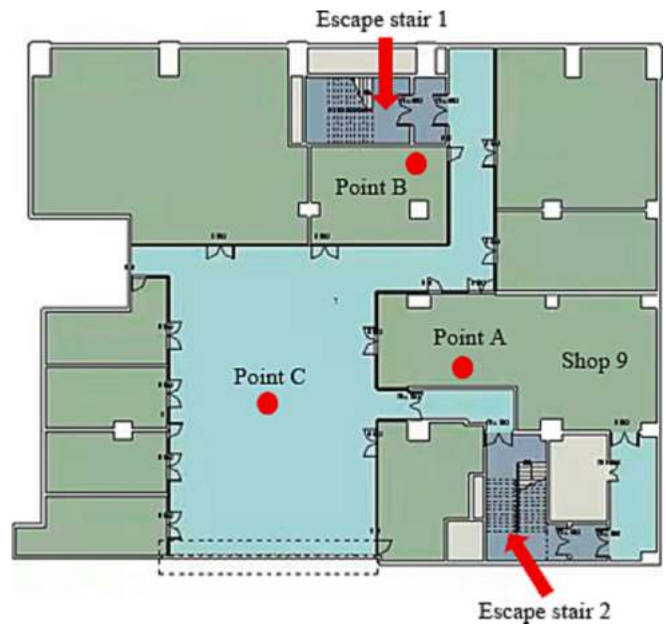


Fig. 6. General layout of the scene.

time will not exceed 30 min [34]. When the CO concentration is 500 ppm, it does not pose a threat to human body [35], so the CO concentration of 500 ppm is taken as one of the criteria for determining the evacuation risk in a fire. According to the type of urban underground commercial street [36], the critical value of visibility is determined as 10 m. The minimum time point when each of the above obstacles causes harm to human body to reach the threshold value is T_{ASET}.

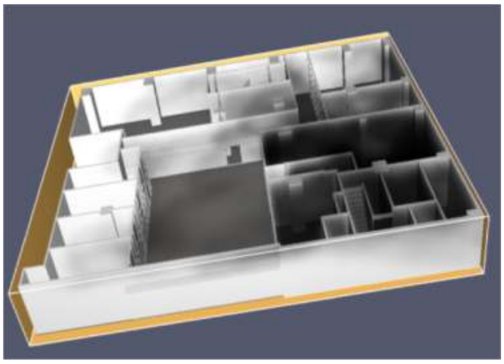
3.3. Simulation analysis of urban underground commercial street fire

In order to observe the fire situation in the urban underground commercial street, measuring slices and detectors are set at 1.5 m high in different scenes. At 150 s, 300 s, 600 s, 1000 s, 1400 s and 1800 s, T_{ASET} is determined by analyzing the change of smoke spread, CO concentration, temperature and visibility during the fire. Use “001b” equipment, “THCP06″ equipment, ”GAS“ equipment and ”Device“ equipment to measure the smoke layer height change, temperature change, CO concentration change and visibility change at stair 1 respectively. Use ”001a“ equipment, ”THCP14″ equipment, “GAS01″ equipment and ”Device01″ equipment to measure the smoke layer height change, temperature change, CO concentration change and visibility change at stair 2 respectively.

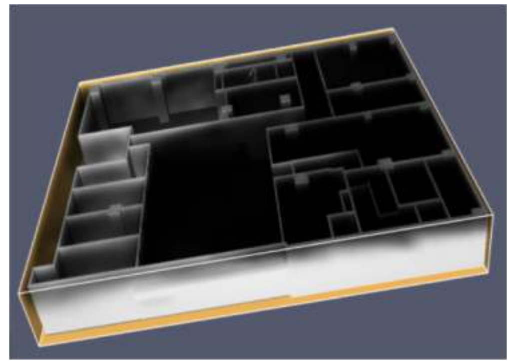
(1) Scenario I

Fig. 7 shows the flow of smoke at 150 s, 300 s, 600 s, 1,000 s, 1,400 s and 1,800 s during the fire at Point A. It can be seen from the figure 150 s when the smoke spreads from store 9 in all directions, at this time the height of the smoke layer will not have a greater impact on the evacuation of people; 300 s when leaning against the stores on this side of store 9 are affected by a greater impact of the smoke through the hall corridor to the opposite side of the stores to continue to spread; 300 s after the smoke almost enveloped the entire commercial area, when the smoke can not continue to spread in all directions, the height of the smoke layer is also getting lower and lower. The height of the smoke layer was getting lower and lower.

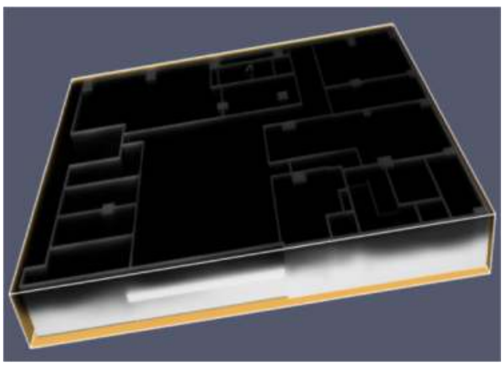
It can be seen from Fig. 8 (a) that after the fire develops to 400 s, the height of the smoke layer changes slightly at about 2.5 m. After the smoke layer reached the lowest point at 100 s, the height of the smoke layer immediately increased to more than 1.5 m. From the perspective of the whole process, the height of the smoke layer is not stable below 1.5



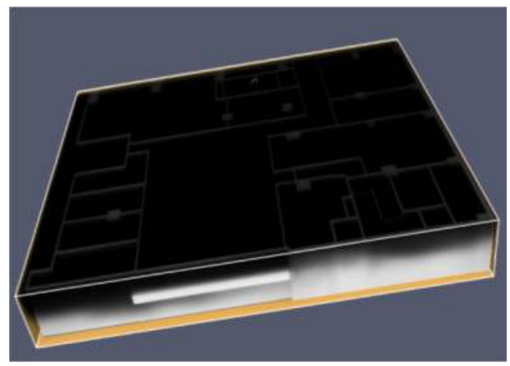
a）Smoke flow in 150 seconds



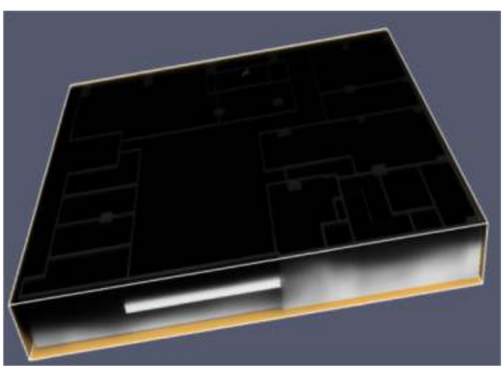
b）Smoke flow in 300 seconds



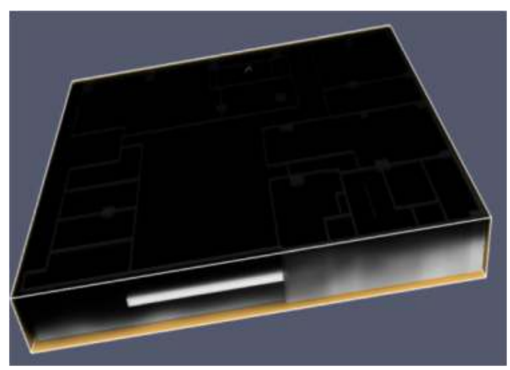
c）Smoke flow in 600 seconds



d）Smoke flow in 1000 seconds

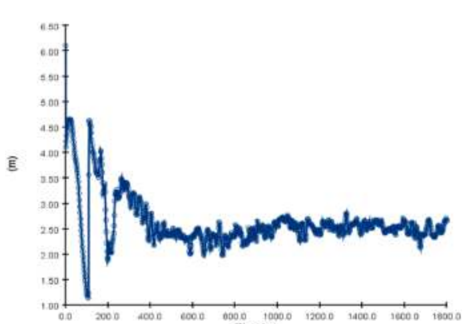


e）Smoke flow in 1400 seconds

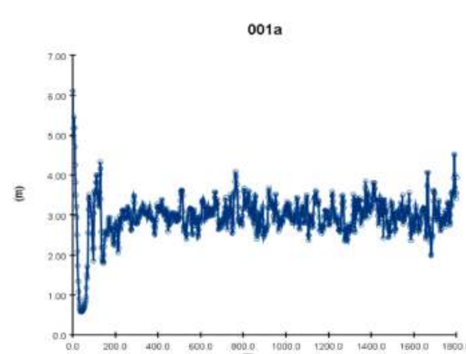


f）Smoke flow in 1800 seconds

Fig. 7. Scenario I smoke spread.



a）Escape stair



b）Escape stair

Fig. 8. Variation curve of smoke layer height in scenario I.

m. Therefore, the height of the smoke layer will not greatly affect the traffic capacity of Escape stair 1 during a fire.

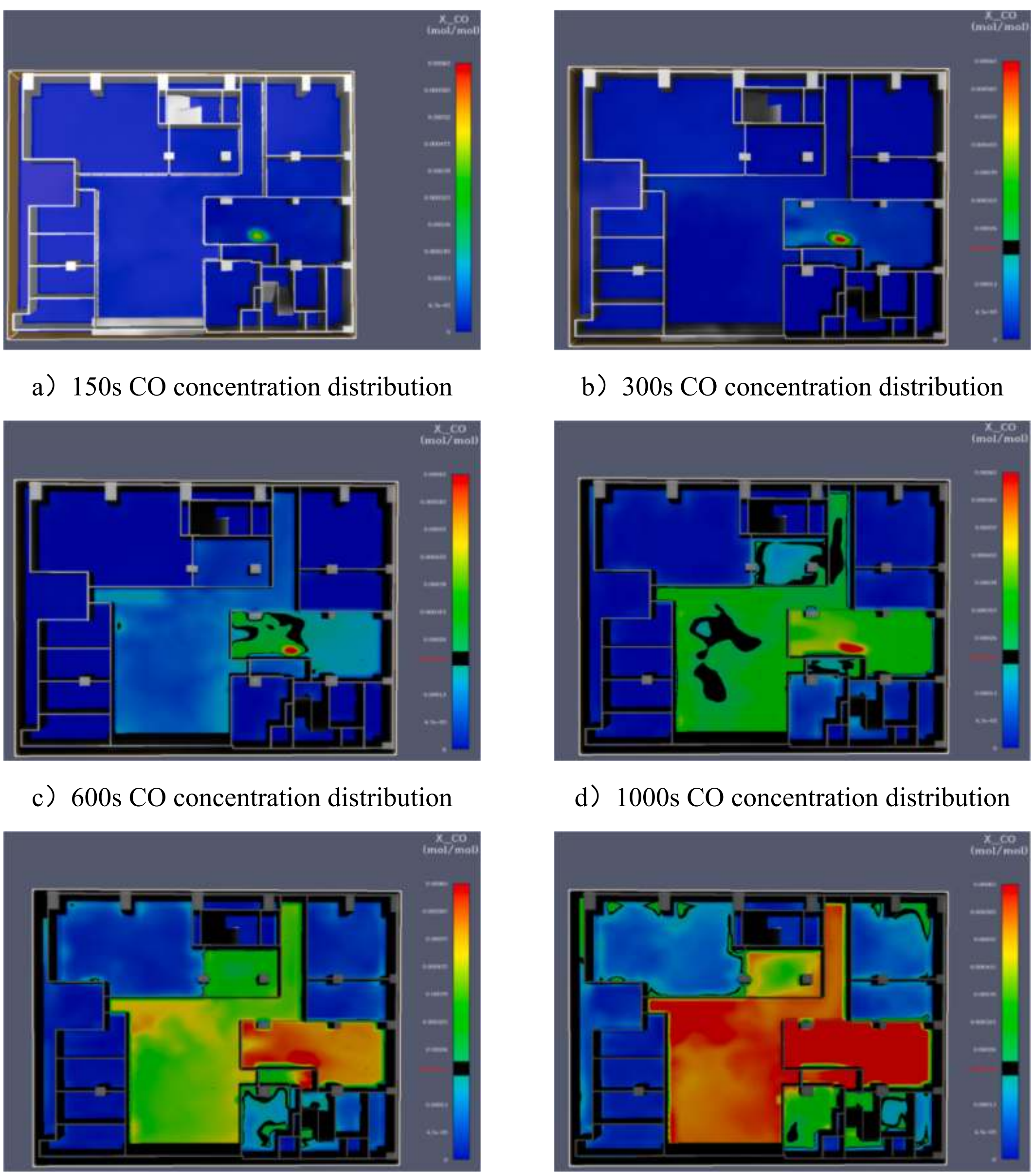
Fig. 8 (b) shows the information, 200 s after the fire, the smoke layer height fluctuates around 2.7 m. Not long after the fire broke out, the smoke layer height of the evacuation staircase 2 was below 1.5 m and immediately returned to above the limit value. This period of time is extremely short and can be ignored. Therefore, the smoke layer height has little influence on the traffic capacity of Escape stair 2.

From the CO concentration cloud images at different times in Fig. 9, it can be seen that as time increases, the area where CO reaches the limit value gradually spreads. When the fire breaks out to about 300 s, the CO concentration in each area will not cause life danger to the personnel, and symptoms such as vomiting and dizziness may affect the evacuation speed; after the fire breaks out to 600 s, the CO concentration changes in shop 9 and hall corridors are more obvious; 1000 s after the fire broke out, the CO concentration in some areas of shop 9 reached 500 ppm, and people could no longer evacuate normally. When the fire occurs to 1400 s close to 1800 s, the main evacuation routes can no longer pass normally, if there are still people who have not been evacuated at this time, the probability of death caused by CO poisoning is high.

From Fig. 10 (a), it can be concluded that the CO concentration at the evacuation staircase 1 is negligible when the fire is about 400 s, and the concentration fluctuates instantaneously at 200 s. After 400 s, the CO concentration is proportional to the time. When the fire broke out to 1620 s, the CO concentration reached the limit value, and Escape stair 1 were no longer passable.

As can be seen from Fig. 10 (b) that the CO concentration at the evacuation staircase 2 was negligible within 180 s after the fire. After 180 s, the CO concentration value increases with the change of time, and the concentration changes greatly at some moments, because it is an instantaneous value, the effect on the human body can be ignored. When the CO concentration reaches the limit value when the fire breaks out to 1350 s, personnel can no longer pass through Escape stair 2.

From the temperature cloud plot of Fig. 11, it can be seen that during the occurrence of a fire, the temperature increase is small, mainly concentrated near the fire source. The temperature in each area and at

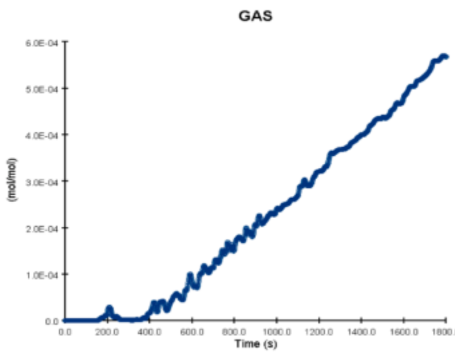


a）150s CO concentration distribution　b）300s CO concentration distribution

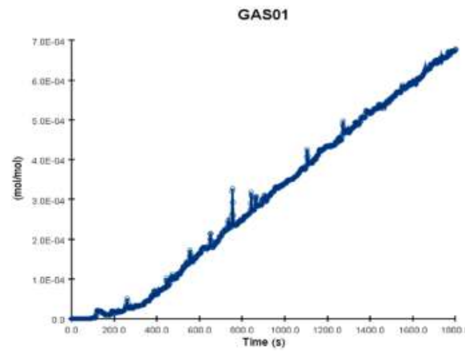
c）600s CO concentration distribution　d）1000s CO concentration distribution

e）1400s CO concentration distribution　f）1800s CO concentration distribution

Fig. 9. CO concentration distribution in scenario I.



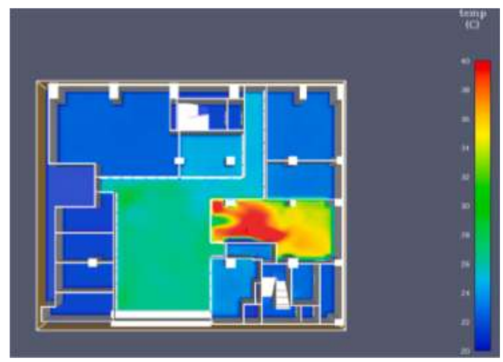
a） Escape stair



b） Escape stair

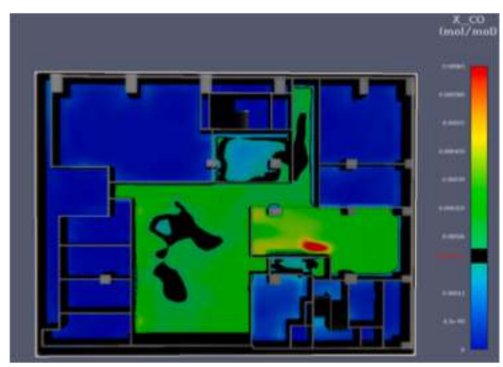
Fig. 10. Change curve of CO concentration in scenario I.

a） 150s temperature distribution

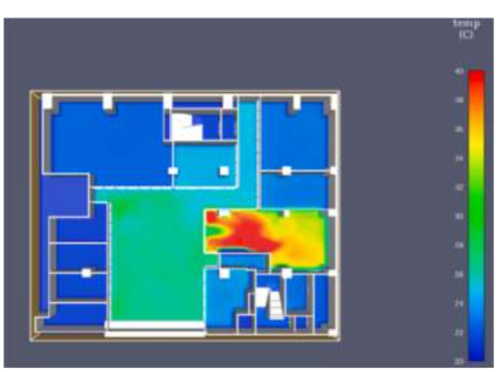


b） 300s temperature distribution

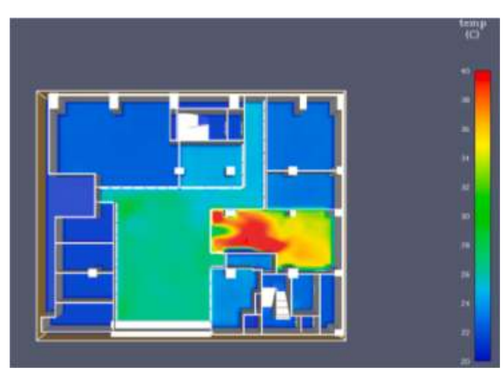
c） 600s temperature distribution



d） 1000s temperature distribution



e） 1400s temperature distribution



f） 1800s temperature distribution

Fig. 11. Temperature distribution diagram of scenario I.

the evacuation exit does not exceed 60° C, and the human body tolerates more than half an hour.

As can be seen from Fig. 12 (a), with the occurrence of fire, the temperature at evacuation staircase 1 remained unchanged for a period of time and then generally increased. The temperature changes in 200–400 s after the fire occur. After burning for 800 s, the temperature changes in a small range around 25 °C. The temperature within 1800 s of the fire does not exceed the limit value, and Escape stair 1 can be passed normally.

Fig. 12 (b) shows that with the occurrence of fire, the indoor temperature generally showed an upward trend, from room temperature 20 °C to a maximum temperature close to 38 °C. During the whole combustion process, the temperature does not exceed 60 °C, so the whole process of Escape stair 2 can be used normally.

The visibility change of each area during the fire can be seen from the visibility cloud chart in Fig. 13. When the fire occurs for 150 s, the visibility of the fire source area has been lower than 10 m. When the visibility of Shop 9 reaches the limit value at about 300 s, the vision of other areas is normal. 300 s after the fire, when it reaches 600 s, Shop 2, Shop 9 and the corridor hall can no longer pass normally, and people's vision is disturbed, so it is difficult to find an evacuation exit for normal evacuation.

As is known in Fig. 14(a) that the visibility of Escape stair 1 is generally decreasing. In about 200 s during the fire, the visibility dropped sharply from 30 m to 10 m and then recovered to 30 m for a period of time. 405 s after the fire, the visibility of Escape stair 1 is lower than the limit value, making evacuation difficult.

According to Fig. 14(b), it can be concluded that the visibility of Escape stair 2 was maintained at 30 m during the initial period of the fire, and then the visibility immediately dropped from 30 m to 17 m in about 180 s, and then gradually decreased until it approached 0 m after falling to 17 m. When the fire broke out to 315 s, the visibility at t Escape stair 2 dropped below the limit value, so people could no longer evacuate from here.

Through the analysis of smoke layer height, CO concentration, temperature and visibility at the evacuation exit in Scenario I, the time when the evacuation stairs are forbidden to pass can be obtained as shown in Table 4.

It can be seen from the above table that Escape stair 1 will stop using 405 s after the fire, and Escape stair 2 will stop using 315 s after the fire. In Scenario I, T_{ASET} is 405 s.

(2) Scenario II

From Fig. 15, it is known that the flow of smoke at the time of 150 s, 300 s, 600 s, 1000 s, 1400 s, and 1800 s during the fire at point B is shown. It can be seen from the figure that the smoke spread from shop 2 to the surroundings at 150 s, among which shop 7 and evacuation stairs 1 were greatly affected. when the fire developed to 300 s, except for the smoke from shops 3, 4, 5 and 6 Less, most areas are filled with smoke. when it reaches 600 s, the entire area is completely covered. after 600 s, the average smoke layer height changes significantly, and when it reaches the limit value, it will affect the evacuation speed or even fail to escape.

As shown in Fig. 16 (a), as the fire spreads, the smoke spreads horizontally from above the fire source to the evacuation stairs 1, and when the smoke accumulates more and more, the height of the smoke layer will decrease. The height of the smoke layer within 0–1800 s is not lower than 1.5 m, so during this period, the smoke layer will not affect the passage of people from Escape stair 1.

From Fig. 16 (b), it can be seen that the smoke layer at Escape stair 2 has a large change within 600 s, and the smoke layer after 600 s is about 3 m. at 150 s, the smoke layer height is only 1.5 m, but the smoke layer height does not tend to Stable, transient, and therefore negligible.

As can be seen from the CO concentration nephogram at different times in Fig. 17 that the CO concentration near the fire source has reached the limit value. During the period from 300 s to 600 s after the fire, the concentration value of Shop 2 and the hall corridor changes first. When the fire broke out for 1400 s, some areas of Shop 2 and the hall corridor had reached 500 ppm, which was more than the acceptable value for human beings. People could not evacuate through these areas. By the time the fire broke out to 1800 s, the main evacuation routes were impassable, and the survival chances of those who had not yet evacuated were slim.

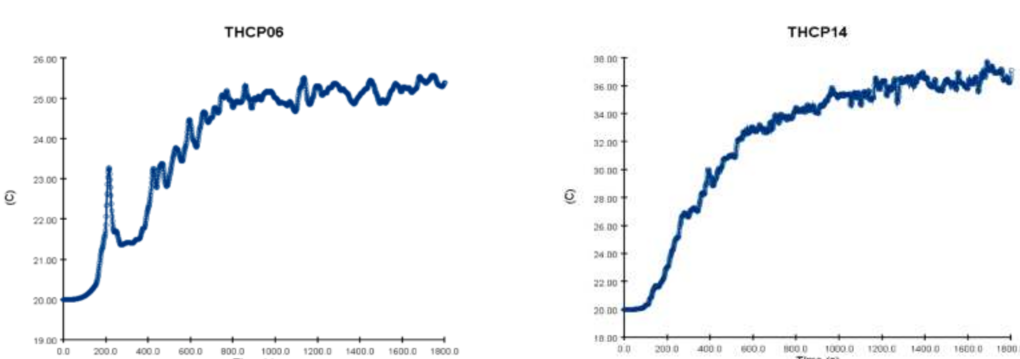
As seen from Fig. 18 (a) that the CO concentration at evacuation stair 1 can be ignored when the fire occurs to about 400 s. After 400 s, CO concentration gradually increased with the increase of time. When the fire occurred to 1660 s, the CO concentration reached the limit value, and Escape stair 1 could not pass.

From Fig. 18 (b), it can be seen that within 500 s after the fire, the CO concentration at Escape stair 2 is negligible. The instantaneous value can ignore the impact on the human body. in the whole process of the simulation process, the CO concentration does not reach the limit value.

It can be seen from the temperature cloud diagram in Fig. 19 that the temperature changes little during the fire, mainly near the fire source of Shop 2. The temperature of Escape stair 1, Escape stair 2 and corridor does not exceed 60 ℃, so the temperature has little impact on personnel evacuation.

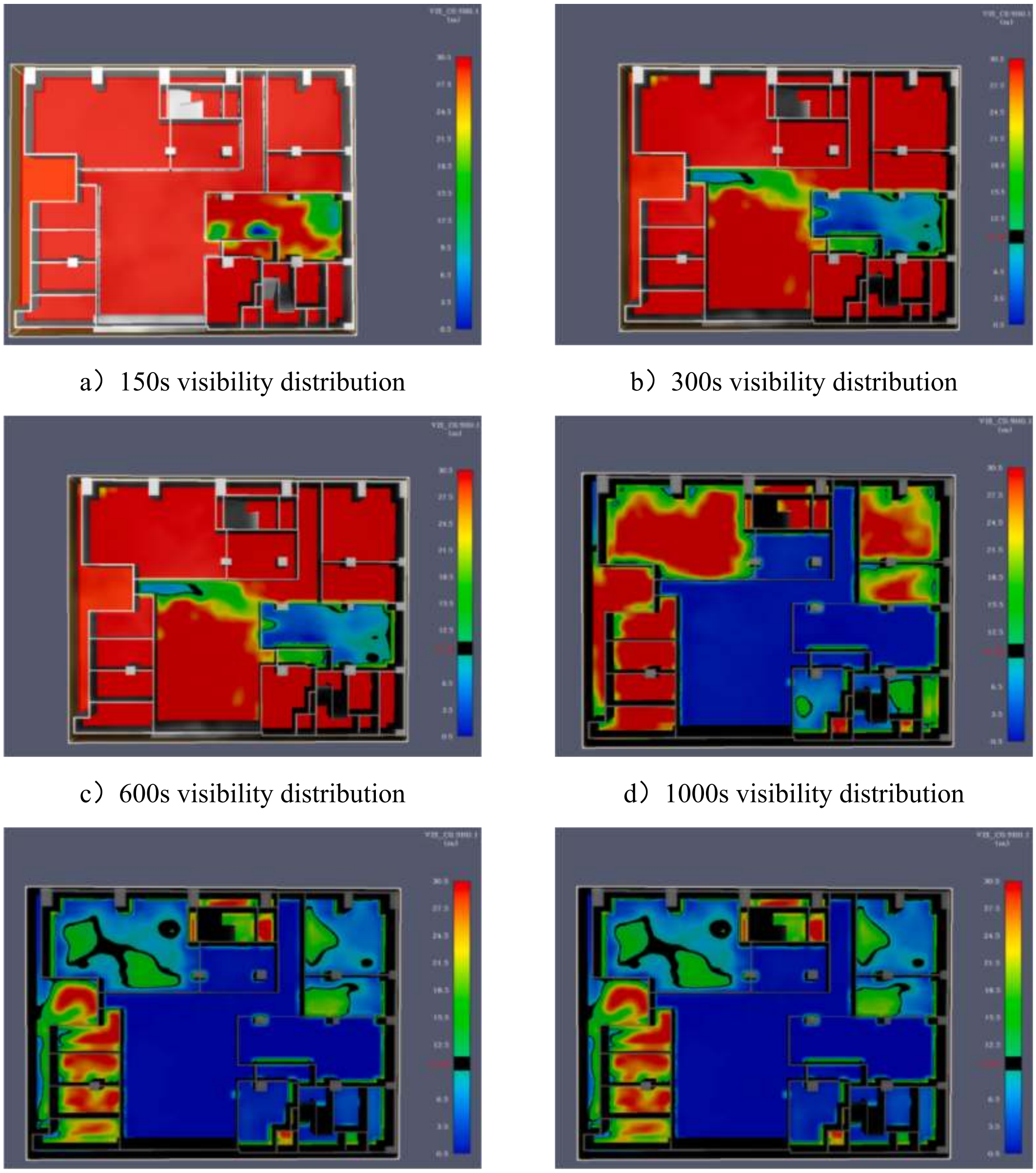
According to the trend in Fig. 20 (a), it can be seen that with the occurrence of fire, the temperature at the evacuation staircase 1 shows an upward trend. After the fire broke out, the temperature changed greatly within 400–500 s. after burning for 800 s, the temperature changed slightly and tended to a straight line. within 1800 s, the temperature did not exceed the limit value, and the evacuation stairs 1 could pass normally.

From the change trend in Fig. 20 (b), it can be seen that with the



a) Escape stair 1 b) Escape stair 2

Fig. 12. Temperature change curve of scenario I.

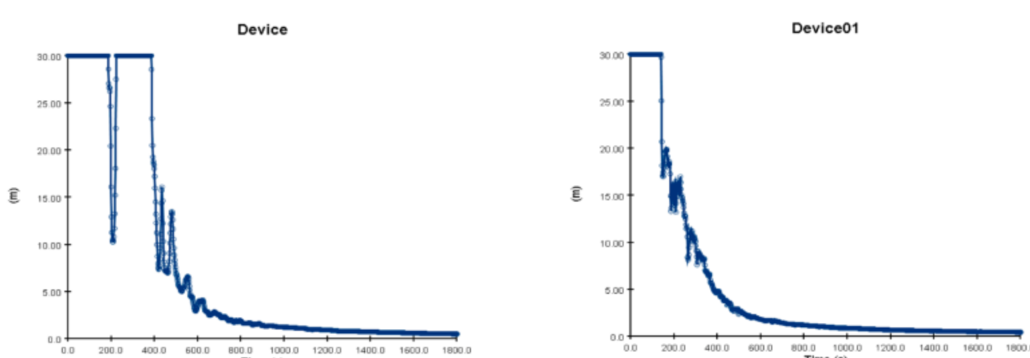


a）150s visibility distribution b）300s visibility distribution

c）600s visibility distribution d）1000s visibility distribution

e）1400s visibility distribution f）1800s visibility distribution

Fig. 13. Visibility distribution map of scenario I.



a） Escape stair 1 b） Escape stair 2

Fig. 14. Visibility change curve of scenario I Fig. 14 visibility change curve of scenarioi.

Table 4
Impact of fire scenario I factors on evacuation exit.

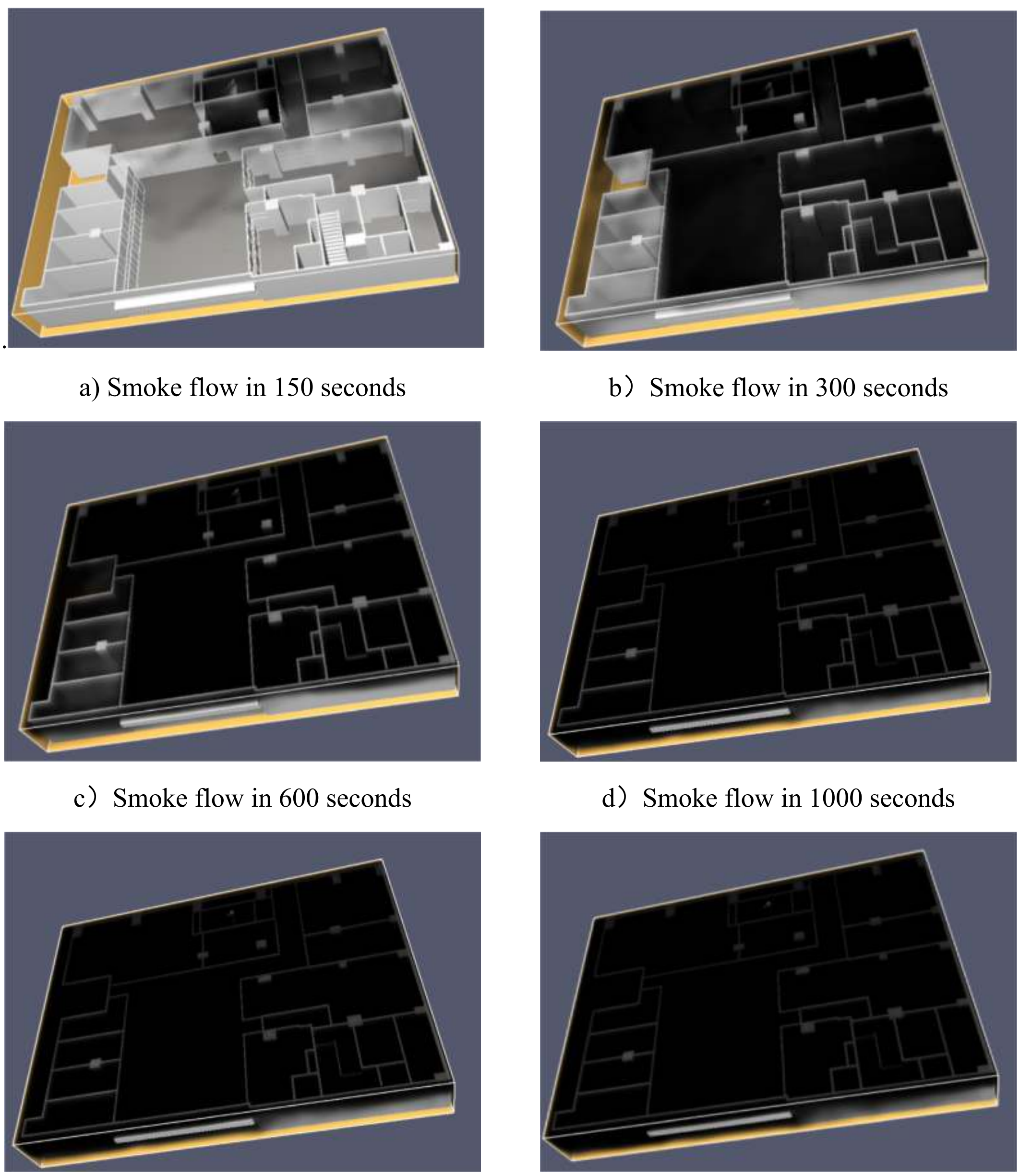
Influence factor	Smoke layer height	CO concentration	Temperature	Visibility
Available time of Escape stair 1	1800 s+	1620 s	1800 s+	405 s
Available time of Escape stair 2	1800 s+	1350 s	1800 s+	315 s

occurrence of fire, the indoor temperature gradually rises from 20 °C. The temperature change of the evacuation staircase 2 is slower than that of the evacuation staircase 1 within 400 s to 500 s after the fire broke out. During the combustion process, the temperature does not exceed 60 °C, and the evacuation staircase 1 can be used normally.

From the visibility cloud map in Fig. 21, we can see the change of visibility in each area during the fire development process. When the fire broke out to 150 s, the visibility near the fire source was low. when the fire broke out to about 300 s, the visibility of part 2 of the store was about 7 m, and the visibility of the part of the hall corridor near Escape stair 2 was close to the limit value, and people should evacuate as soon as possible. The line of sight in other areas is normal. when it reaches 600 s, the visibility of shop 2 and the passage leading to the evacuation stairs is too low, and the line of sight of personnel is disturbed, making it difficult to observe the surrounding environment and make evacuation difficult.

By the Fig. 22 (a) shows that the visibility of Escape stair 1 is 30 m within 405 s after the fire, and then the visibility starts to decrease. When the fire broke out for 470 s, the visibility dropped to 10 m or less. Therefore, Escape stair 1 cannot be used normally after 470 s.

Can know by the Fig. 22 (b) that the visibility of Escape stair 2 changes sharply 590 s after the fire. From 590 s to 682 s after the fire, the visibility decreases from 30 m to 10 m. After 682 s, the escape from Escape stair 2 was blocked, and the visibility did not meet the escape requirements.



a) Smoke flow in 150 seconds

b） Smoke flow in 300 seconds

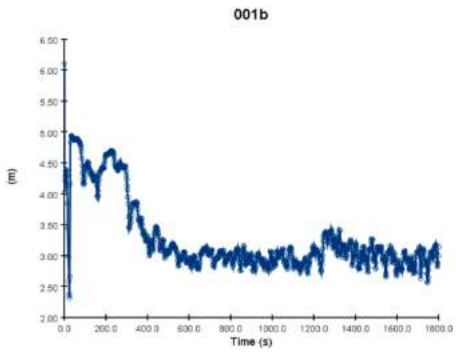
c） Smoke flow in 600 seconds

d） Smoke flow in 1000 seconds

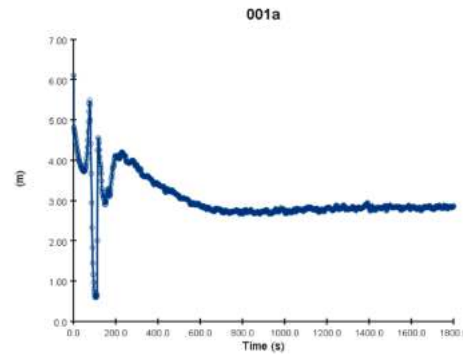
e） Smoke flow in 1400 seconds

f） Smoke flow in 1800 seconds

Fig. 15. Scenario I smoke spread.



a) Escape stair 1

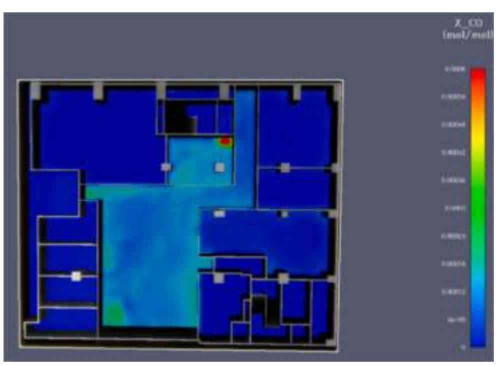


b) Escape stair 2

Fig. 16. Variation curve of smoke layer height in scenario I.

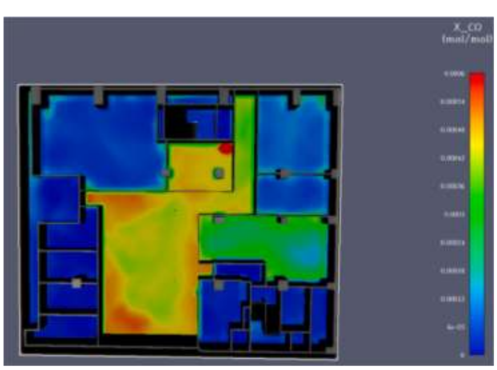
a) 150s CO concentration distribution

b) 300s CO concentration distribution

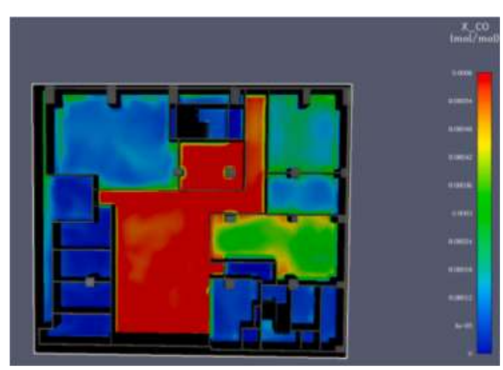


c) 600s CO concentration distribution

d) 1000s CO concentration distribution

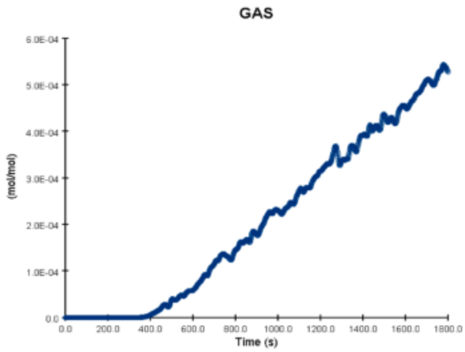


e) 1400s CO concentration distribution

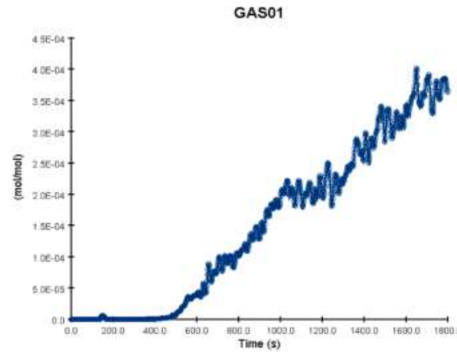


f) 1800s CO concentration distribution

Fig. 17. CO concentration distribution in scenario II.



a）Escape stair 1

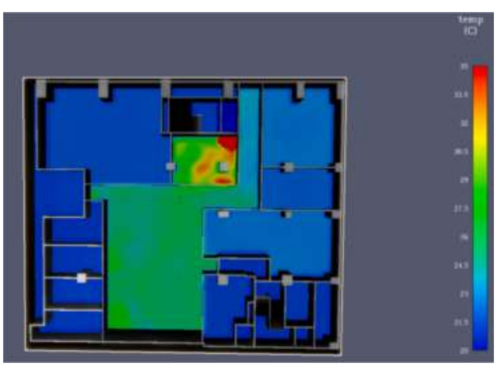


b）Escape stair 2

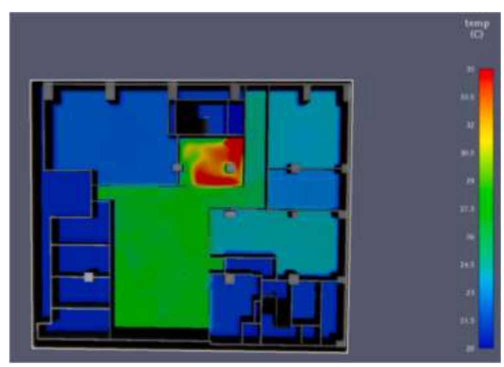
Fig. 18. Change curve of CO concentration at scene II evacuation stair 1.

a）150s temperature distribution

b）300s temperature distribution



c）600s temperature distribution

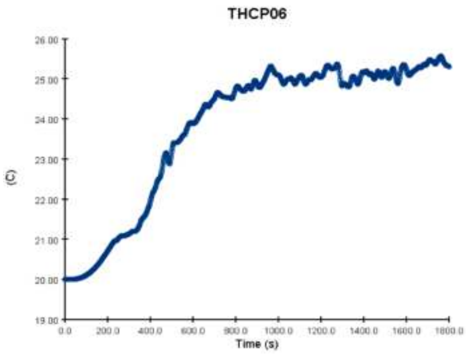


d）1000s temperature distribution

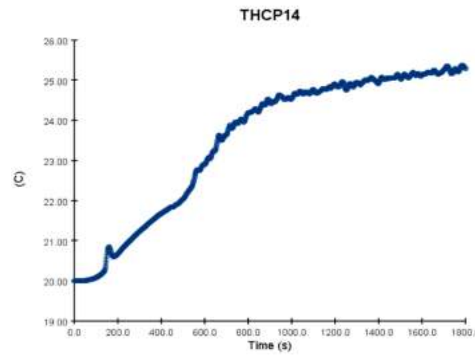
e）1400s temperature distribution

f）1800s temperature distribution

Fig. 19. Temperature distribution in scenario II.



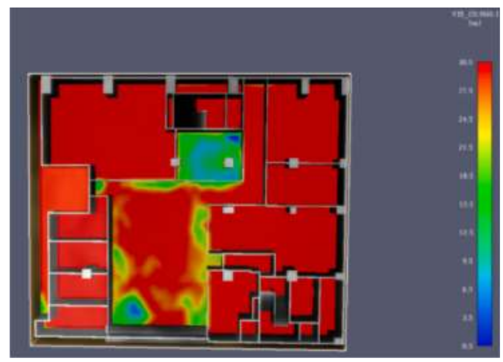
a） Stair 1



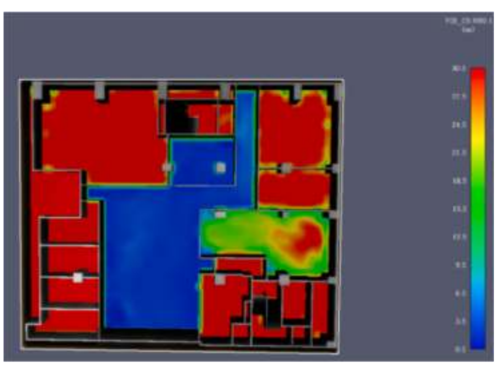
b） Stair 2

Fig. 20. Temperature change curve of scene II evacuation stair 1.

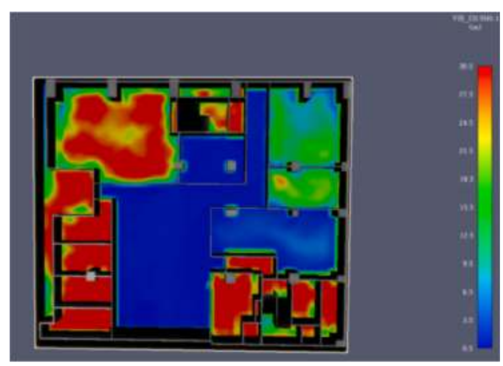
a）150s visibility distribution



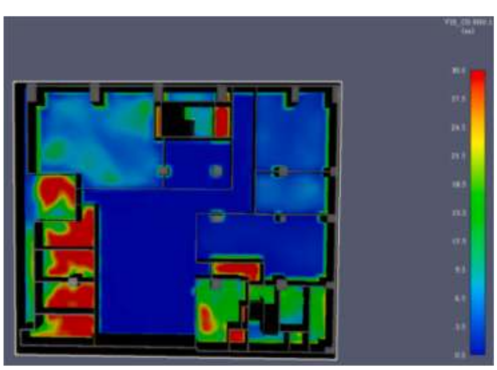
b）300s visibility distribution



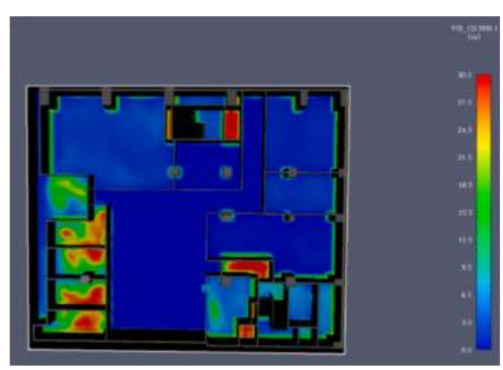
c）600s visibility distribution



d）1000s visibility distribution

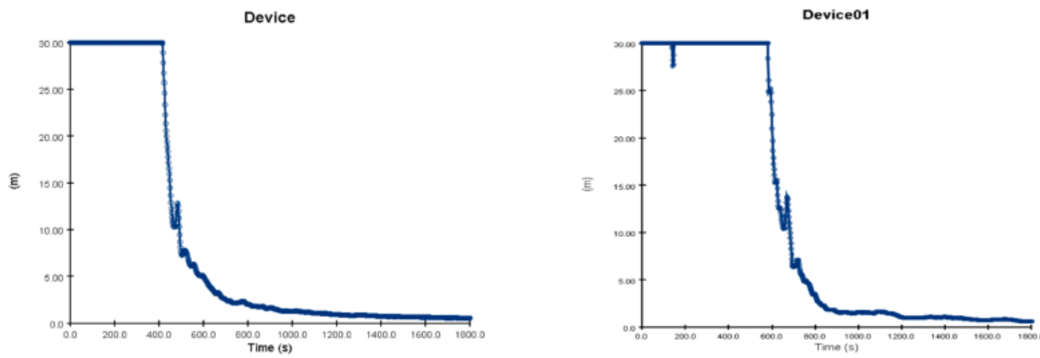


e）1400s visibility distribution



f）1800s visibility distribution

Fig. 21. Visibility distribution in scenario II.



a） Escape stair 1　　b） Escape stair 1

Fig. 22. Visibility change curve at scene II evacuation stair 1.

According to the analysis of smoke layer height, CO concentration, temperature and visibility at the evacuation exit of Scenario II, the time when the evacuation stairs are forbidden to pass can be obtained as shown in Table 5.

It can be seen from the above table that evacuation stair 1 will not be used 470 s after the fire, and evacuation stair 2 will not be used 682 s after the fire. T_{ASET} for personnel in Scenario II is 682 s.

(3) Scenario III

Fig. 23 shows the smoke flow at 150 s, 300 s, 600 s, 1000 s, 1400 s and 1800 s during the fire at point C. Smoke diffuses from the fire source in the hall corridor in 150 s during the fire. By 300 s, the smoke has spread to most parts of the commercial street. At this time, there is less smoke in shops 7, 8 and the upper part of the evacuation stairs, so you can see the surrounding environment clearly. By 600 s, the smoke had continued to spread downward. When the height of smoke layer was low, people could not walk upright, which increased the difficulty of evacuation.

As can be seen from Fig. 24 (a) that the smoke layer height fluctuates frequently 265 s after the fire. During the fire, the height of smoke layer drops to below 1.5 m at some times, but the height immediately recovers to above the limit value. It can be seen from the smoke layer change curve that the smoke layer height is more than 1.5 m most of the time after 265 s, so the influence of smoke layer height on evacuation stairs is not considered.

As Fig. 24 (b) shown that the smoke layer at Stair 2 changes greatly within 190 s. When the fire occurs to 337 s, the smoke layer height tends to be stable and reaches the limit value of 1.5 m. When the height of the smoke layer is less than 1.5 m, people cannot escape. Therefore, Escape stair 2 will not pass after 337 s.

It can be seen from the CO concentration cloud diagram in Fig. 25 that the CO concentration near the fire source has reached the limit value within 300 s from the fire to the fire, and the indicators in other areas are normal. After 300 s, the CO concentration in hall corridor, shop 2 and shop 9 will change preferentially. When the fire occurs for 1400 s, some areas of Shop 2, Shop 9 and the hall corridor have reached the limit value. When the fire broke out to 1800 s, all areas of Shop 2, Shop 9 and the hall corridor had reached the limit value and could not be evacuated through these areas.

Table 5
Impact of fire scenario II factors on evacuation exit.

Influence factor	Smoke layer height	CO concentration	Temperature	Visibility
Available time of Escape stair 1	1800 s+	1660 s	1800 s+	470 s
Available time of Escape stair 2	1800 s+	1800 s+	1800 s+	682 s

It can be seen from Fig. 26 (a) that the CO concentration of evacuation stair 1 is positively correlated with the time after the fire occurs for 200 s. When the CO concentration reaches the limit value, the fire has occurred for 1425 s. Therefore, when the fire occurred 1425 s later, people could not evacuate through Escape stair 1.

It can be seen from Fig. 26 (b) that during the fire, the CO concentration of Escape stair 2 fluctuates more than that of Escape stair 1. When the fire broke out for 1410 s, the CO concentration of Escape stair 2 reached the limit value, and people could no longer tolerate evacuation from this stair.

It can be seen from the temperature cloud diagram in Fig. 27 that the maximum temperature during a fire is 40 ℃, which does not exceed the temperature that can be tolerated by the human body. The fire source temperature is rising and the heating area is spreading to the hall corridor. The temperature of Escape stair 1, Escape stair 2 and main evacuation routes did not exceed 60 ℃, so the temperature had little impact on personnel evacuation.

As shown in the Fig. 28 (a), the temperature of Escape stair 1 is basically unchanged from the beginning to 200 s, then rises rapidly after 200 s, and finally becomes stable around 400 s. The maximum temperature reaches 30 ℃, which has little impact on personnel evacuation.

It can be seen from Fig. 28(b) that the temperature of evacuation stair 2 basically did not change in the first 200 s of the fire, but rose rapidly after 200 s. The temperature fluctuated greatly between 250 s and 600 s, and became stable after 700 s. The maximum temperature reached during the fire is 29 ℃, which has no impact on personnel evacuation.

As can be seen from Fig. 29 that the highest visibility can reach 30.5 m during the fire. When the fire occurs to 150 s, the visibility at the center of the fire source is less than 10 m, and the visibility near the fire source is about 10 m. When the time is about 300 s, the visibility of some areas of Shop 2 and the hall corridor is about 7 m, and the visibility of Shop 9 starts to change. When it reaches 600 s, the visibility of Shop 2, Shop 9 and the evacuation exit is below 10 m, and it is difficult for people to find the evacuation exit accurately through the evacuation sign. Only a small part of the shops have normal vision 600 s after the fire, and the main evacuation routes are not conducive to traffic.

By Fig. 30 (a) known, after the fire, the smoke will take some time to reach the position of Escape stair 1. The visibility of Escape stair 1 remains unchanged at 30 m for a certain period of time, and then at a certain time, the visibility rapidly decreases until it reaches 0 m. When the fire occurs to 235 s, the visibility of Escape stair 1 is 10 m. Therefore, after the fire breaks out for 235 s, people cannot evacuate normally through Escape stair 1.

As shown in Fig. 30 (b), the visibility change trend of Escape stair 2 is basically consistent with that of Escape stair 1. The instantaneous change range of visibility is large at some time within 200–400 s after

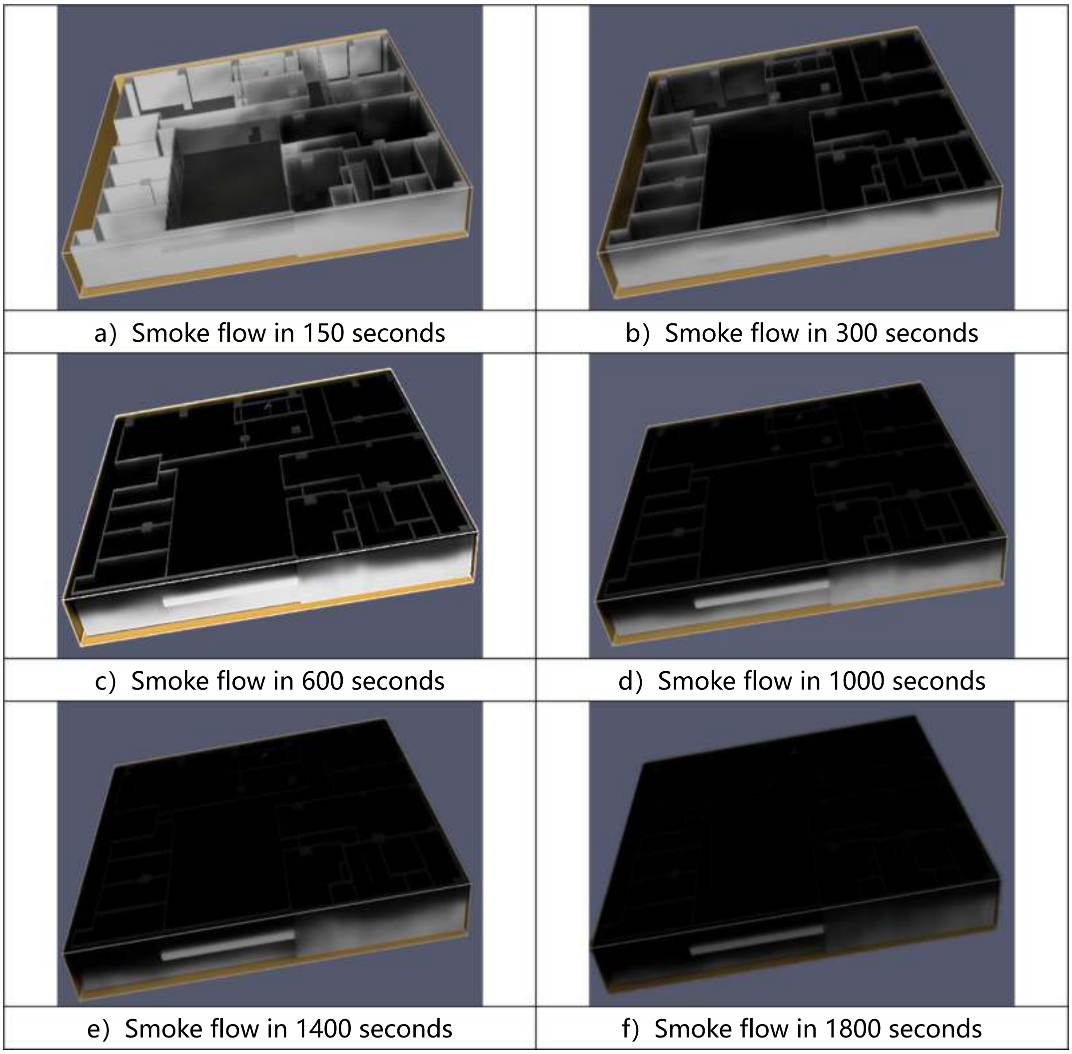


Fig. 23. Scenario III Smoke spread.

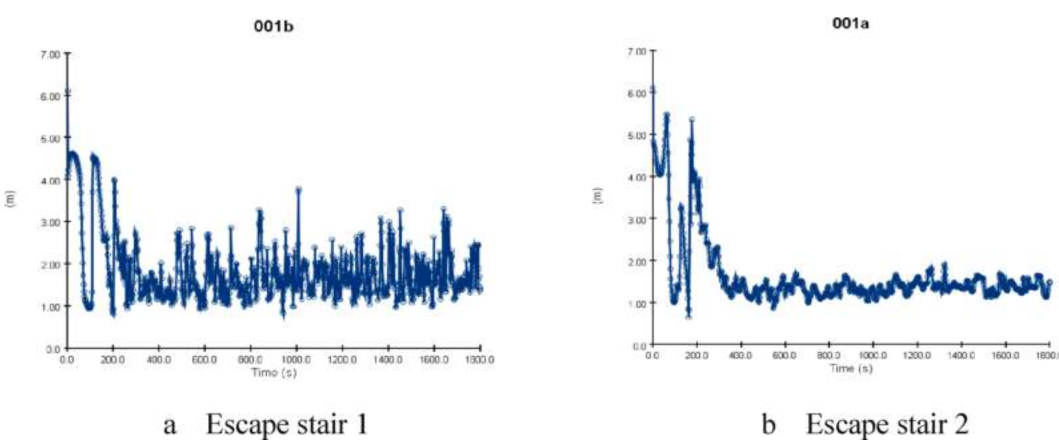


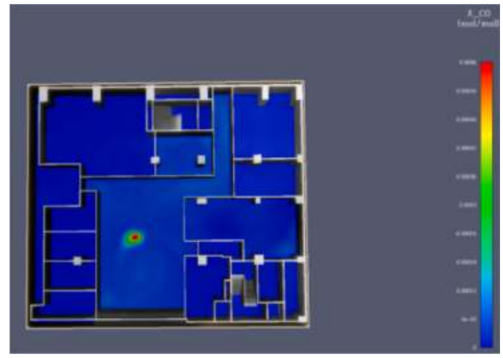
Fig. 24. Change curve of smoke layer height at scene III evacuation stair 1.

the fire. When the fire occurs to 285 s, the visibility drops below 10 m. Therefore, when the fire develops to 285 s, Escape stair 2 is not conducive to the passage of people.

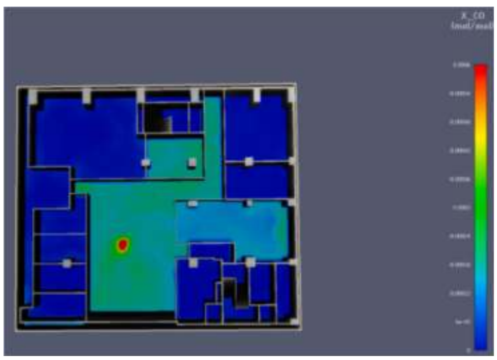
According to the analysis of smoke layer height, CO concentration, temperature and visibility at the evacuation exit of Scenario III, the time when the evacuation stairs are forbidden to pass can be obtained as shown in Table 6.

It can be seen from the above table that Escape stair 1 will not be used after 235 s of the fire, and Escape stair 2 will not be used after 285 s of the fire. T_{ASET} in Scenario III is 285 s. The results obtained by summarizing the three scenarios are shown in Table 7. By comparing the time when evacuation stair 1 and evacuation stair 2 stop using in these

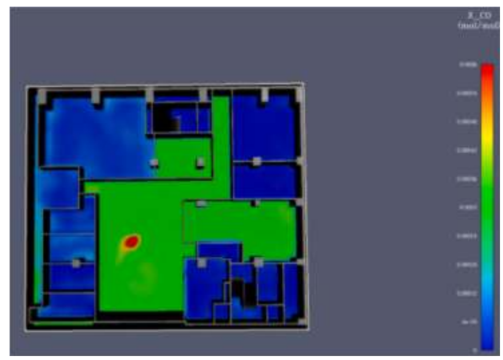
a) 150s CO concentration distribution



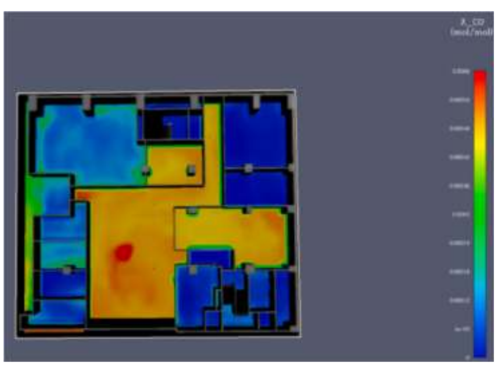
b) 300s CO concentration distribution



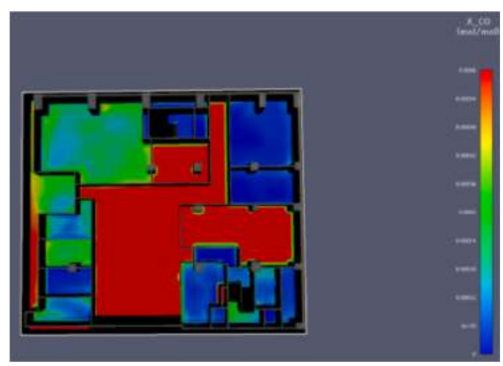
c) 600s CO concentration distribution



d) 1000s CO concentration distribution

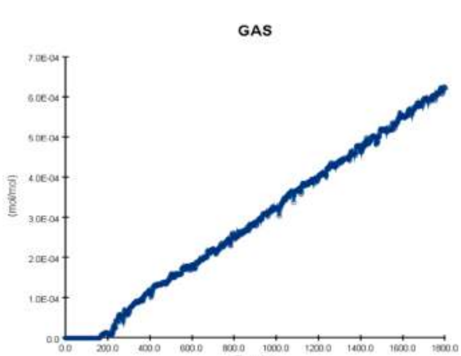


e) 1400s CO concentration distribution

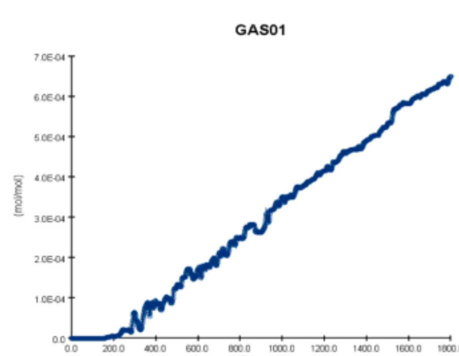


f) 1800s CO concentration distribution

Fig. 25. Scenario III CO concentration distribution.



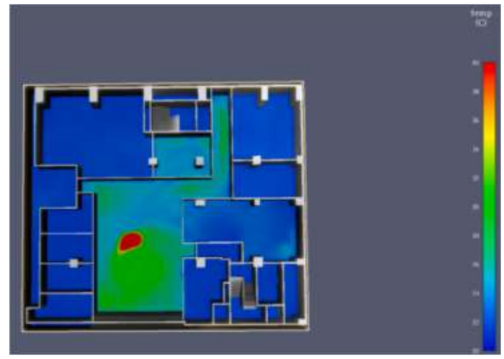
a) Escape stair 1



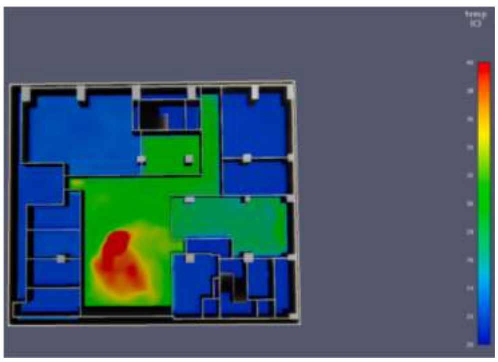
b) Escape stair 2

Fig. 26. Change curve of CO concentration at scene III evacuation stair 1.

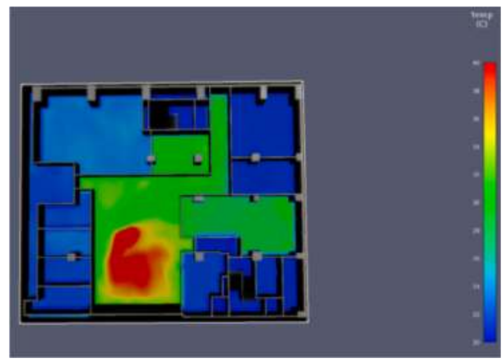
a) 150s temperature distribution



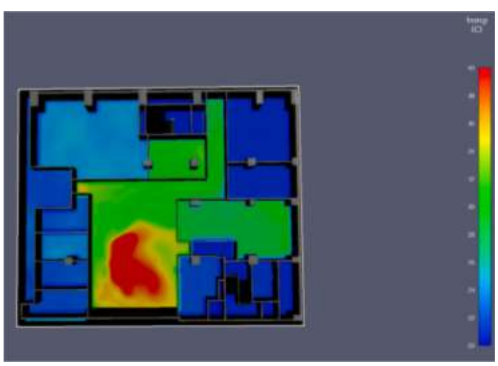
b) 300s temperature distribution



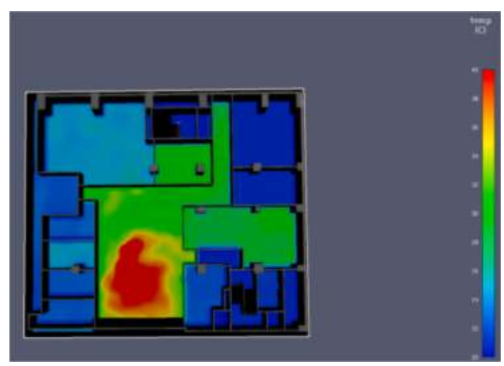
c) 600s temperature distribution



d) 1000s temperature distribution

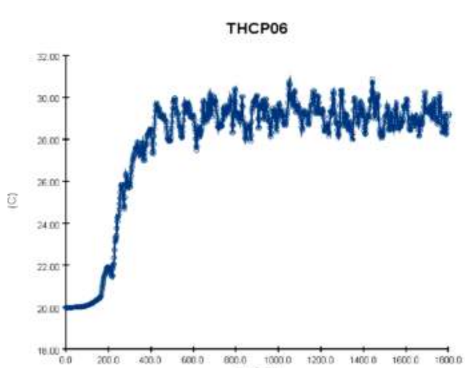


e) 1400s temperature distribution

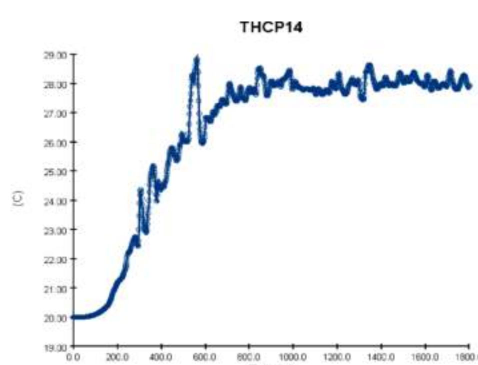


f) 1800s temperature distribution

Fig. 27. Temperature distribution in scenario III.



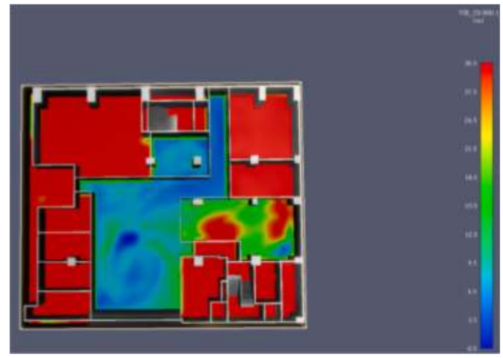
a Escape stair 1



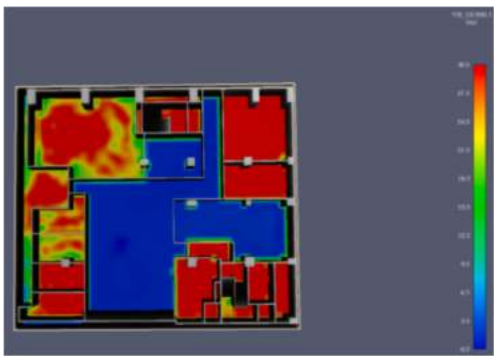
b Escape stair 1

Fig. 28. Temperature change curve of scene III evacuation stair 1.

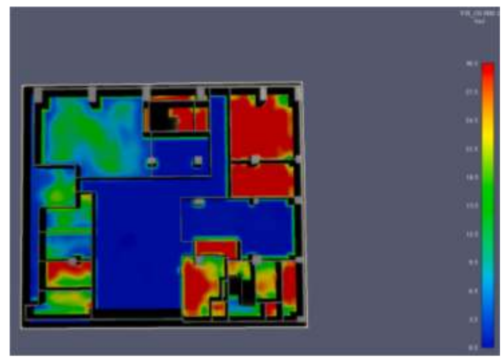
a) 150s visibility distribution



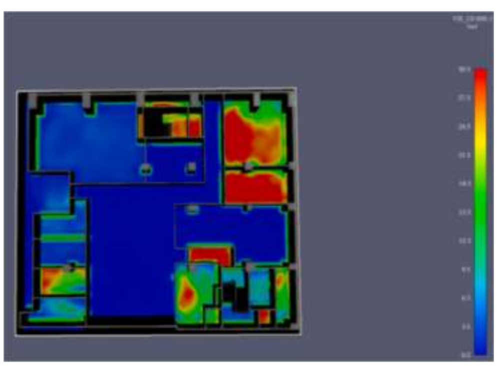
b) 300s visibility distribution



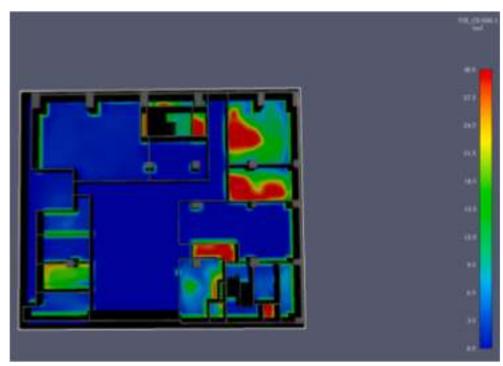
c) 600s visibility distribution



d) 1000s visibility distribution

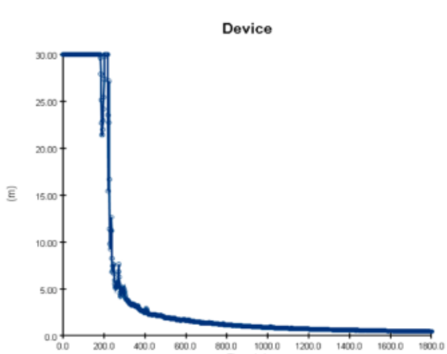


e) 1400s visibility distribution

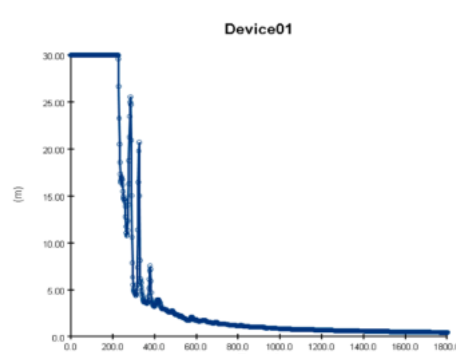


f) 1800s visibility distribution

Fig. 29. Visibility distribution map of scene III.



a) Escape stair 1



b) Escape stair 2

Fig. 30. Visibility change curve of scene III.

Table 6
Impact of Fire Scenario III Factors on Evacuation Exit.

Influence factor	Smoke layer height	CO concentration	Temperature	Visibility
Available time of Escape stair 1	1800 s+	1425 s	1800 s+	235 s
Available time of Escape stair 2	337 s	1410 s	1800 s+	285 s

three scenarios, and then taking the most unfavorable value, it is finally concluded that Escape stair 1 stops using 235 s after the fire, and Escape stair 2 stops using 285 s after the fire. By comparing the impact of CO concentration, temperature and visibility on the evacuation time under these three scenarios, the T_{ASET} is selected according to the adverse principle. T_{ASET} is calculated to be 285 s. Analyze the four fire prevention areas of urban underground commercial street, select the fire prevention area with the most unfavorable evacuation as the simulation area, and set three fire sources in the simulation area as different fire scenarios. Import the BIM model into PyroSim, set parameters and detectors for different scenes, and then simulate the three scenes, analyze the time when smoke layer height, temperature, CO concentration and visibility cause danger to people under different scenes, obtain the traffic capacity of each exit and determine T_{ASET} of urban underground commercial street.

4. Discussion

(1) The fire source location is set at point A (in shop 9), point B (in shop 2, close to the evacuation staircase 1) and point C (in the center of the hall corridor) as three scenarios of fire. Taking fire compartment, I of the urban underground commercial street as the prototype, PyroSim fire simulation software is used to analyze the impact of various parameters of the fire process on personnel evacuation.

  (1) When the fire source is set at point C, it has the greatest impact on personnel evacuation. The lobby corridor is the main route for people to the evacuation stairs. Once a fire occurs, the smoke will spread to the non fire area, and eventually form a chimney benefit at the evacuation stairs. Therefore, smoke control measures should be taken at the evacuation stairs, and fire prevention and supervision efforts should be further strengthened for the main evacuation routes and firefighting measures should be taken.

Table 7
Summary results for three scenarios.

	Influence factor	Smoke layer height	CO concentration	Temperature	Visibility
Scenario I	Available time of Escape 1	1800 s+	1620 s	1800 s+	405 s
	Available time of Escape 2	1800 s+	1350 s	1800 s+	315 s
Scenario II	Available time of Escape 1	1800 s+	1660 s	1800 s+	470 s
	Available time of Escape 2	1800 s+	1800 s+	1800 s+	682 s
Scenario III	Available time of Escape 1	1800 s+	1425 s	1800 s+	235 s
	Available time of Escape 2	337 s	1410 s	1800 s+	285 s

  (2) Through the analysis of the changes of CO concentration, temperature and visibility in the three scenarios, the effect of fire products on evacuation is obtained: visibility > CO concentration > smoke layer height > temperature.

  (3) Under the most unfavorable principle, the available safe evacuation time of each scene is calculated according to the expression of available safe evacuation time, and the available safe evacuation time of urban underground commercial street is 285 s. Escape stair 1 shall stop using 235 s after the fire, and Escape stair 2 shall stop using 285 s after the fire.

(2) In the process of fire safety evacuation design of urban underground commercial street, administration should not only reasonably design and plan according to the existing building design specifications, but also rely on the actual situation of the building to carry out fire safety work, so as to improve the safety and reliability of urban underground commercial street. At the same time, effective early warning mechanisms and emergency plans should be formulated with "prevention first".

Visibility has the highest degree of impact on safe evacuation; when a fire occurs, smoke and flames cause reduced visibility in evacuation routes and exits, making the evacuation process difficult and dangerous. Provide obvious directional signs and emergency evacuation instructions, such as emergency exit signs and evacuation arrows, in evacuation routes and exits. These instructions should be sufficiently reflective to be clearly visible in smoke.

CO is a colorless, odorless and non-irritating toxic gas, and high concentrations can seriously affect the human respiratory system and central nervous system. It is essential to install carbon monoxide detectors inside underground shopping streets, especially in areas where CO is potentially generated. Ensure that there is an adequate ventilation system so that CO can be vented quickly.

The impact of the height of the smoke layer on fire evacuation should not be ignored, and the installation of reliable automatic smoke alarm systems in urban underground spaces can detect smoke and sound an alarm at an early stage. Early detection of fire provides more time to evacuate people and reduces the impact of smoke on evacuation.

Temperature is another important factor in fire evacuation, and the onset of a fire is often accompanied by an increase in temperature. In the process of building design and construction, consideration should be given to the use of fire-resistant materials and technologies to ensure the fire resistance of the building structure. At the same time, buildings should be equipped with suitable fire separation areas and evacuation routes to reduce the possibility of fire spread.

5. Conclusion

This paper takes the safe evacuation of an underground commercial street in Fuzhou City A as the research object to carry out the simulation research on fire and evacuation. The simulation framework is established based on BIM technology, and the advantages of digital technology that can store complete building construction information are used to make up for the shortcomings of fire dynamic simulator and emergency evacuation system. The interaction of building information is realized and the impact of fire products on crowd evacuation is studied. A new research idea is proposed for emergency evacuation simulation.

By analyzing and selecting the most unfavorable evacuation area in fire compartment I–IV, and taking advantage of BIM technology in safe evacuation, information transfer between BIM and FDS tools and evacuation simulation software is realized. PyroSim software is used to simulate the whole process of regional fire, analyze the parameters in the fire process such as smoke spread, smoke layer height change, CO concentration, temperature and visibility under different fire scenarios, and obtain the time when each evacuation stair is out of service and the available safe evacuation time.

Urban underground shopping streets usually have complex layouts and structures, including multi-story buildings, maze-like corridors and entrances. Establishing an accurate evacuation model requires consideration of these complex factors and detailed modeling and simulation. However, due to the complexity of data collection and modeling, as well as the limitation of computational resources, evacuation modeling may be difficult for large-scale urban underground shopping streets. This shortcoming can be customer service in the future through cutting-edge technologies such as big data and artificial intelligence.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors gratefully acknowledge the financial support provided by General projects of China National Social Science Foundation (grant number: 22BGL237).

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