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Article

Numerical simulation study on fire combustion of advertising board materials in airport terminals

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ABSTRACT

In order to meet the guidance, publicity, and commercial functions, various types of billboards have become important permanent facilities in the airport terminal, which are distributed all over the terminal. The advertising materials inside billboards have certain fire hazards, and there is a lack of research on the fire risk of advertising materials at present. Therefore, it is necessary to study the fire risk of advertising materials in airport terminals. Taking PVC board, a commonly used advertising material, as the research object, Pyrosim was used to model and analyze its fire, and the characteristics of fire spread, smoke flow, and distribution of combustion products such as CO and CO_2 in the terminal building were obtained. This study explores the fire combustion characteristics of advertising materials in civil airport terminals, providing a basis for fire prevention management in civil airport terminals.

1. Introduction

The airport terminal is an important large-scale infrastructure for civil aviation transportation and urban construction. As the most crowded area of the airport, once a fire accident occurs, it will directly affect the airport terminal's normal operation and personnel travel [1-3]. The occurrence of an airport fire has strong suddenness, uncertainty, and consequences [4, 5]. Because the types of combustibles in each public area of the airport terminal are different. These combustibles have different geometric thicknesses, ignition temperatures, thermal conductivity, unit heat release, and smoke release characteristics. There are different fire potential and combustion characteristics in the combustion process. Therefore, it is necessary to evaluate the fire risk of different functional areas of the terminal building and study the combustion characteristics of different types of combustibles to improve the performance of the fire safety system of the terminal building [4-7]. Based on the fire occurrence process of different functional areas, many scholars have carried out different material ignition points to study the smoke occurrence and fire spread during the fire occurrence of the airport terminal. Yuan et al. [4] used FDS to conduct full-scale modeling and numerical simulation of store shelves, bookstore shelves, check-in common seats, and business desks and chairs in civil airport terminals. They analyzed the correlation between fire load and temperature. Song et al. [8] used FDS to simulate the fire at the airport terminal and obtained the parameters of smoke spread, temperature, CO_2, and CO under two conditions with or without a spray system. The simulation results accurately reflect the dynamic process of fire and provide support for the formulation of an airport fire emergency plan. HU et al. [9] used CFAST and FDS to simulate the smoke-filling process in the domestic boarding-arrival channel with an aspect ratio of about 52.3 at the international airport terminal. The flame impact time, smoke temperature distribution, and temperature distribution of the airport fire were predicted. Men et al. [10] simulated the smoke dispersion pattern and control effect of each terminal floor under the existing smoke control strategy through FDS. The results show that the current smoke strategy of the airport terminal is reasonable, which can achieve effective smoke exhaust in the fire scene and ensure the safety of personnel. Dong Yao [11] analyzed the terminal building from the structure, use, and internal combustibles of the airport building, evaluated the risk of fire and whether the prevention and control technology was effective, analyzed the evacuation characteristics and evacuation safety, reduced losses and environmental protection, and proposed corresponding improvement measures. Song Yang et al. [8] analyzed the layout of the building in the terminal building. When the mechanical smoke exhaust system was not started in time, a fire occurred during the peak period of the flow of people, and the evacuation was not affected by thermal radiation. However, the smoke height decreased faster, which would pose a significant threat to safety. The above scholars have simulated fire accidents in airport terminals for different functional areas of the airport. However, in recent years, many fire accidents have occurred at home and abroad due to the burning of billboards in airport terminals. This kind of fire has greater fire hazards and more serious consequences. This article establishes a partial model of the terminal building based on the actual situation of the airport, which is widely used in commercial advertising. Taking PVC board, a commonly used advertising material, as the research object, Pyrosim is used to model and analyze its fire, and the characteristics of fire spread and smoke flow in the terminal building were obtained. This study can fill the gap in research on the combustion characteristics of advertising materials, provide ideas and references for the fire hazard assessment of similar materials, and provide theoretical support and reference for the fire safety management and legal regulations of airport terminals.

2. Combustion model

2.1 Combustion material model

Solid materials can be divided into thin and thick materials according to their thickness. Thin materials refer to materials that are thin enough to ignore temperature gradients in the thickness direction, assuming that the temperature of the material is equal in the thickness direction. Materials with a thickness of less than 3mm under normal conditions can be considered thin materials. The thickness of advertising materials is generally below 2mm, which meets the definition of thin materials. Therefore, the combustion model of advertising materials is consistent with that of thin materials. If the heating condition is that one side of the thin material is heated while the other side is insulated, the ignition time is:

$$t_{ig} = \frac{d\rho c}{h} . ln\left(\frac{T_f - T_0}{T_f - T_{ig}}\right) \quad (1)$$

If the heating condition is that one side of the thin material is heated while the other side is not heated, the ignition time is:

$$t_{ig} = \frac{d\rho c}{h} \cdot ln\left(\frac{T_f - T_0}{T_f + T_0 - 2T_{ig}}\right) \quad (2)$$

In the formula, t_{ig} is the ignition time, s; *d* is the material thickness, m; *h* is the convection heat transfer coefficient, kW / (m^2.K); *c* is the heat capacity, J / (kg.K); ρ is the material density, kg/m^3; T_0 is the initial temperature of the material surface, °C; T_{ig} is the material ignition temperature, °C; T_f is the heating temperature of the material surface, °C.

2.2 Pyrosim model establishment

The terminal building modeled in this article mainly uses high-performance reinforced concrete, steel pipes, and aluminum components, while the ground advertising materials are mainly PVC boards. Establish a local Pyrosim model for its basement level, as shown in Figure 1. Based on the actual structural characteristics of the area, the grid setting conditions are determined as follows:

The minimum value of the X-axis is 322 m, and the maximum value is 430 m. The minimum value on the Y-axis is 136m, and the maximum value is 197 m. The minimum value of the Z-axis is -6 m, and the maximum value is 0 m. A cube grid has been established, with individual grid sizes of 0.5m × 0.5m × 0.5m, totaling 316224. The actual size of the model is around 6000 m^2.

2.3 Analysis model

The main component of PVC board is polyvinyl chloride. According to its combustion reaction equation:

Fuel + Air = Products

In the formula, Fuel is C_2H_3Cl, Air is $1.53O_2 + 5.76N_2$ and Products is $HCl + H_2O + 0.14CO + 0.96CO_2 + 0.9C + 5.76N_2$.
Setting C_2H_3Cl as the combustion reactant, according to its combustion characteristics, its combustion phenomenon is more intense, and the heat release is greater. The model environment temperature is set to room temperature of 20 °C, atmospheric pressure of 1atm, reaction combustion heat of 16400 kJ/kg, and HRRPUA of 750 kW/m^2. The fire source is set on the surface of the PVC advertising decorative floor on the basement level of the terminal building, on a two-dimensional plane with a size of 2m × 3m. There are a total of 2 fire sources, with a color of dark brown and red. The location of the fire source is shown in the model in Figure 1. In addition, PVC advertising decorative flooring is shown as pink flooring in Figure 1.

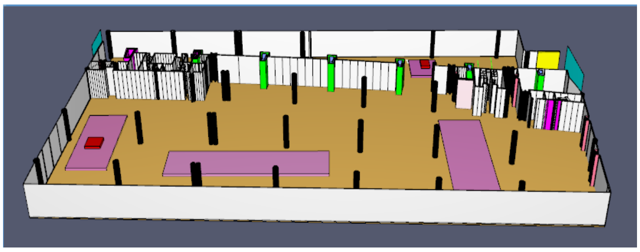

Figure 1. Model scaling sample

2.4 Model parameters

This article mainly measures the distribution of carbon monoxide concentration, fire temperature distribution, carbon dioxide concentration distribution, corresponding conditions of the automatic sprinkler system, and smoke distribution on the underground floor of the terminal building. Install a smoke concentration slice at the aisle with Y=158 to detect the distribution of smoke concentration in the hall; Install a temperature slice at the aisle with Y=190 to detect temperature changes in the aisle; Install carbon monoxide concentration detectors at X=330m, Y=158m, Z=-2m and X=396m, Y=178m, Z=-2m respectively to detect changes in carbon monoxide concentration at the ignition point and entrance of the hall. Install a carbon dioxide concentration detector at X=423m, Y=182m, Z=-2m and X=327m, Y=193m, Z=-2m, respectively, to detect the concentration changes of carbon dioxide at the entrance and exit of the aisle. The placement of each slice and detection device is shown in Figure 2.

3. Results and discussions

3.1 Automatic sprinkler fire extinguishing system

According to the fire safety technical specifications, if the terminal building with less than 15000m2 is equipped with combustible advertising materials, it should also be equipped with an automatic sprinkler fire extinguishing system.

According to relevant regulations, the building hazard level is medium hazard level, and the water spray intensity is set to at least 6L/(min · m^2). This article designs two sets of automatic sprinkler fire extinguishing systems based on different water spray intensities, referred to as System A and System B. The water spray intensity of system A is set to 6L/(min · m^2), and the water spray intensity of system B is set to 8L/(min · m^2).

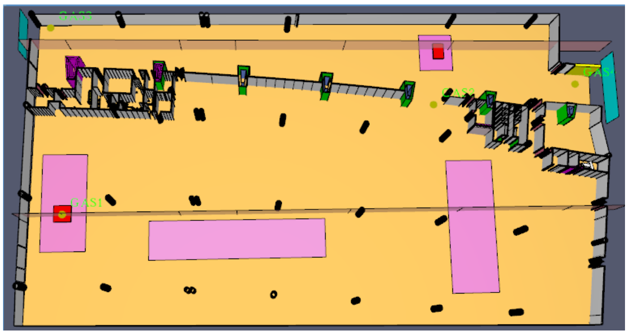

Figure 2. Layout of detection device

3.1.1 System parameters and modeling

According to the actual situation of the building, automatic sprinkler system A adopts a hanging and expanded coverage type nozzle arranged in a square shape. A nozzle flow coefficient K=100, working pressure 0.1 MPa, spray flow rate 100 L/min. Then the nozzle spacing a,

$a=(100/6)^{0.5}=4.08$m

Minimum spray radius of nozzle c,

$c=4.08^{0.5}=2.02$m

According to the specifications, the distance between the nozzle and the wall is set between 0.1m and 2.4 m, and the nozzle is set at 0.1 m from the top plate. Therefore, the distance between the nozzle and the underground floor is 5.9 m. Due to the maximum protection area of the nozzle being 23 m^2, the maximum protection radius of the nozzle is r,

$r=(23/\pi)^{0.5}=2.70$m

The actual spray radius R of the nozzle should meet the following requirements,

$2.02 \le R \le 2.70$

The spray angle Θ should meet the following requirements,

$\Theta_{min} \ge$ acrtan（2.02/5.9）≈19°

$\Theta_{max} \le$ acrtan（2.70/5.9）≈24°

So, the injection angle Θ∈ [19 °, 24 °] is taken as Θ=20 °.

Set the starting temperature of the nozzle to room temperature of 20 ℃ and the starting temperature to 74 ℃. The main parameters of the automatic sprinkler fire extinguishing system have been set, and the remaining parameters are set to the default values of the system. The Pyrosim model is established as shown in Figure 3.

3.1.2 Parameters and modeling of system B

Analogous to System A, System B also uses a drooping, expanded coverage nozzle with a square layout. A nozzle flow coefficient K=100, working pressure 0.1MPa, spray flow rate 100L/min. Then, the nozzle spacing a is $a=(100/8)^{0.5}=3.54$m. The minimum spray radius of nozzle c is $c=3.54^{0.5}=1.88$m.

According to the specifications, the distance between the nozzle and the wall is set between 0.1m and 2.4 m, and the nozzle is set at 0.1 m from the top plate. Therefore, the distance between the nozzle and the underground floor is 5.9 m. Due to the maximum protection area of the nozzle being 23 m^2, the maximum protection radius r of the nozzle is,

r=(23/π)0.5=2.70 m

The actual spray radius R of the nozzle should meet the following requirements, $1.88 \le R \le 2.70$

The spray angle Θ should meet the following requirements,

Θmin≥acrtan（1.88/5.9）≈18°

Θmax≤acrtan（2.70/5.9）≈24°

So, the injection angle Θ∈ [18 °, 24 °] is taken as Θ=20 °.

Set the starting temperature of the nozzle to room temperature of 20 ℃ and the starting temperature to 74 ℃. The main parameters of the automatic sprinkler fire extinguishing system have been set, and the remaining parameters are set to the default values of the system. The Pyrosim model is established as shown in Figure 4.

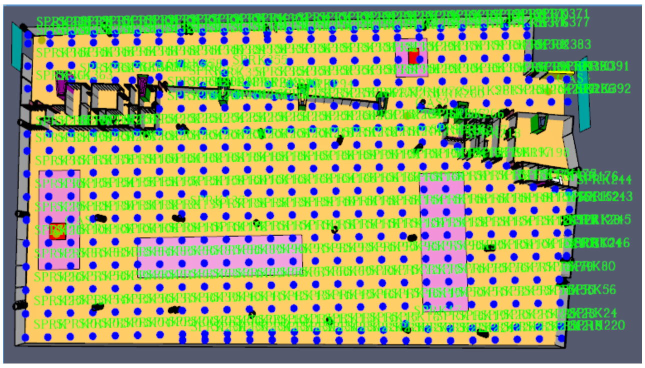

Figure 3. The model of system A

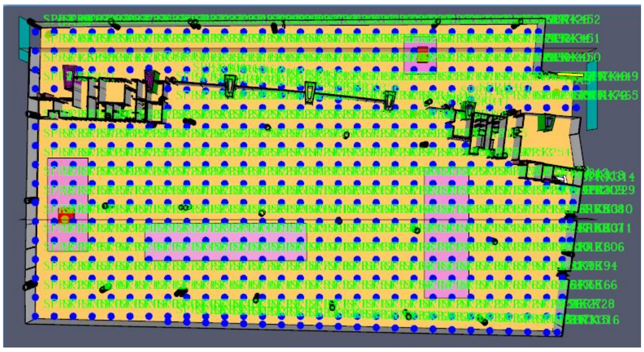

Figure 4. The model of system B

3.2 Fire scene parameter simulation and analysis

3.2.1 Simulation and analysis of system A

According to the 3D fire simulation animation in Smokeview, it is found that when the PVC advertising decorative panel on the ground starts to burn, the smoke of the fire first spreads vertically. After contacting the top plate, the smoke from the top begins to spread horizontally in all directions, forming a roof jet phenomenon. At t=10s, the smoke generated by the burning point in the hall begins to spread to the right side of the open hall due to the obstruction of the surrounding walls. The smoke generated by the burning point in the aisle not only spreads to both sides of the aisle but also to the entrance of the hall, as shown in Figure 5. At t=30 s, the smoke has spread to half of the hall, but the smoke concentration at the entrance is relatively low, as shown in Figure 6. The smoke in the aisle has taken up most of the space and is blocked by buildings, such as the wall and door on the right side of the aisle.

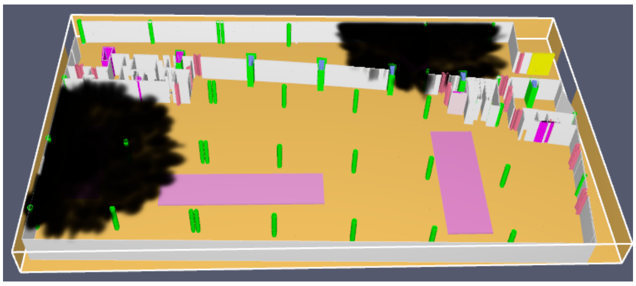

Figure 5. Smoke spreads at t=10 s

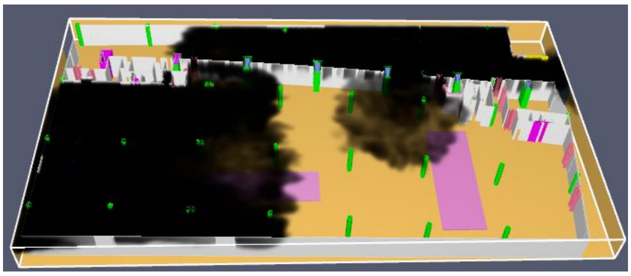

Figure 6. Smoke spreads at t=30 s

At t=45 s, the smoke in the hall has occupied about most of the space and is about to spread throughout the entire hall. In addition, smoke has spread to the left entrance and exit in the hallway, as shown in Figure 7. At t=88s, the entire model is completely covered by smoke except for the areas enclosed by smoke prevention and control facilities, such as walls and doors, as shown in Figure 8.

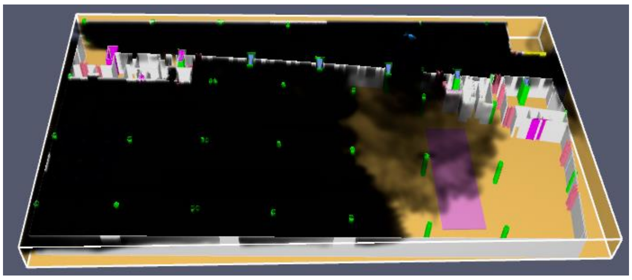

Figure 7. Smoke spreads at t=45 s

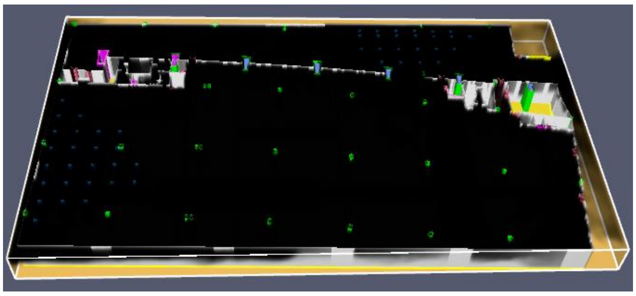

Figure 8. Smoke spreads at t=88 s

3.2.2 Simulation and analysis of system B

It is not difficult to observe in the 3D fire simulation animation in Smokeview that the combustion phenomenon of PVC advertising decorative panels in System B is similar to that in System A. At t=10 s, the smoke generated by the PVC advertising decorative panel spreads vertically to the top plate, forming a ceiling jet, and the smoke gradually spreads horizontally, as shown in Figure 9. At t=31s, smoke occupies about half of the space in the hall, and the smoke generated by the entrance walkway covers it. The smoke in the aisle is similar to the situation of System A, occupying the majority of the aisle space and being blocked at the exit on the right side of the aisle, as shown in Figure 10. At t=48 s, although the majority of the space in the hall is filled with smoke, the concentration of smoke spreading from the aisle is relatively low, and a high concentration of smoke occupies the general space in the hall. In addition, the aisle has been completely covered by smoke, as shown in Figure 11. At t=89 s, the entire model is basically covered by smoke except for a small area protected by smoke prevention and control facilities, as shown in Figure 12.

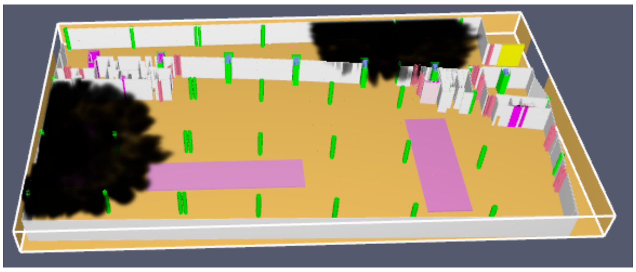

Figure 9. Smoke Spread at t=10s

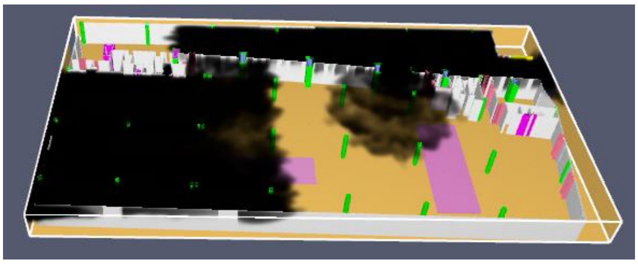

Figure 10. Smoke spreads at t=31 s

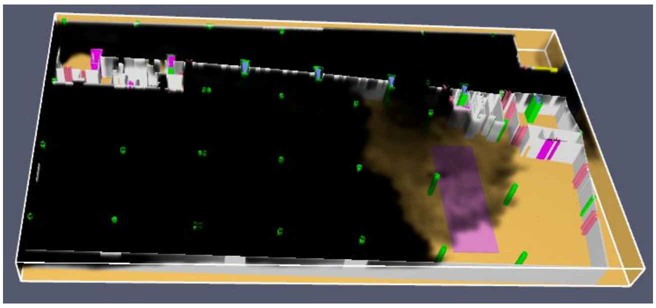

Figure 11. Smoke spreads at t=48s

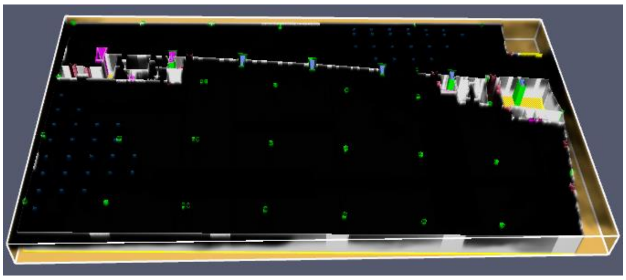

Figure 12. Smoke spreads at t=89 s

3.2.3 Comparison and analysis of system A and system B

Through 3D smoke view fire simulation animation, it is found that although System B has higher water spray intensity and better performance, the phenomenon of smoke spread between the two is very similar in the simulation, and the difference is not significant. From the perspective of controlling smoke spread alone, System A has a higher cost-effectiveness. In addition, it is easy to observe from the 3D fire simulation animation that the spread speed of fire smoke is very rapid. Although this model has a large space of 6000 m^2 and is equipped with an automatic sprinkler system, the fire smoke still covered the entire model in less than 2 minutes. Due to the presence of fire smoke, visibility in the fire scene decreased. Therefore, when a fire occurs, in order to evacuate the people in the fire as much as possible, personnel should be quickly organized to evacuate during the fire to prevent the spread of high-temperature smoke from causing casualties or people being trapped in the fire due to reduced visibility, and to ensure the safety of personnel as much as possible.

3.3 Startup and analysis of automatic sprinkler fire extinguishing system

3.3.1 Simulation and analysis of system A

At t=12 s, the nozzles near the burning point in the hall start spraying water to extinguish the fire, as shown in Figure 13. At t=17 s, the nozzle located near the burning point in the aisle starts to extinguish the fire, as shown in Figure 14. At t=40 s, as the combustion progresses, the nozzles near the combustion point begin to respond one after another, as shown in Figure 15. At t=90s, the nozzles near the combustion point were activated extensively. Although the surface of the PVC advertising decorative floor at the combustion point was covered with water, the advertising material that was already burning was still burning violently, as shown in Figure 16.

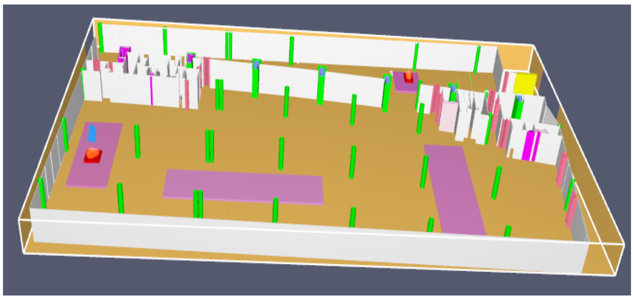

Figure 13. Starting status of automatic sprinkler fire extinguishing system at t=12s

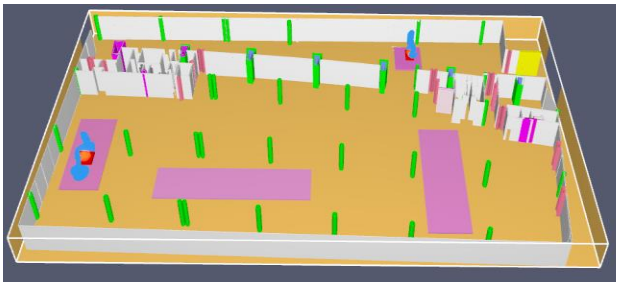

Figure 14. Starting status of automatic sprinkler fire extinguishing system at t=17s

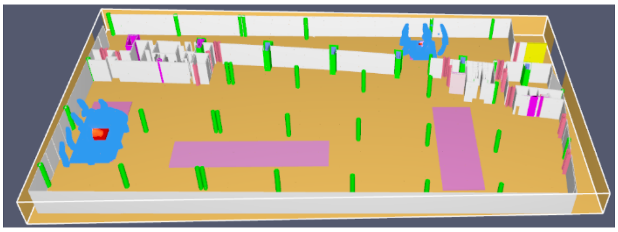

Figure 15. Startup status of automatic sprinkler fire extinguishing system at t=40s

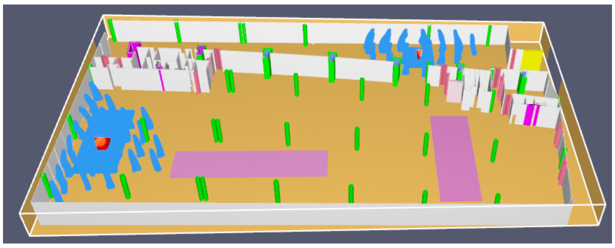

Figure 16. Starting status of automatic sprinkler fire extinguishing system at t=90s

At t=181 s, almost all the nozzles on the left side of the combustion point in the hall responded, and about 40% of the nozzles in the aisle had already responded. In addition, the sprinkler heads at the entrance of the aisle and hall have been activated to start spraying water for fire extinguishing, as shown in Figure 17. At t=240s, the water sprayed by the hall nozzle not only completely covered the surface of the PVC advertising decorative floor at the combustion point but also partially covered the surface of the PVC advertising decorative floor in the middle of the hall. The number of response nozzles in the aisle has also increased, as shown in Figure 18.

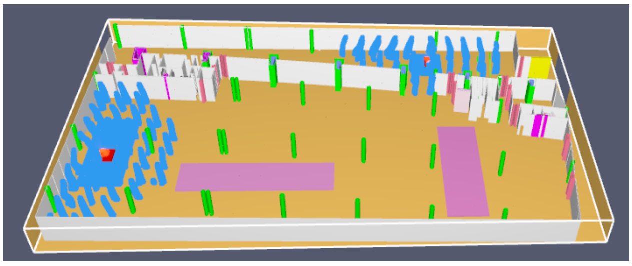

Figure 17. Starting status of automatic sprinkler fire extinguishing system at t=181s

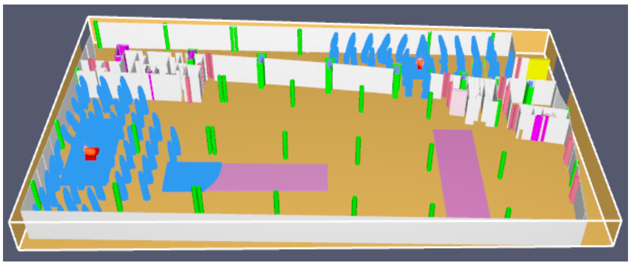

Figure 18. Startup status of automatic sprinkler fire extinguishing system at t=240s

3.3.2 Simulation and analysis of system B

At t=10s, the nozzle near the combustion point in the hall is activated for the first time, as shown in Figure 19. At t=11s, the nozzle near the burning point in the aisle is activated for the first time to extinguish the fire, as shown in Figure 20. At t=35 s, the nozzle near the combustion points in the hall responded, and the overall water spray increased. More than half of the PVC advertising decorative floor at the burning point of the hall has been covered by water, and the PVC advertising decorative floor at the burning point of the aisle has been completely covered by water, as shown in Figure 21. At t=90 s, although the nozzle response degree near each combustion point of System B is further expanded, the PVC advertising decorative floor covered with water on the surface is still burning vigorously, as shown in Figure 22.

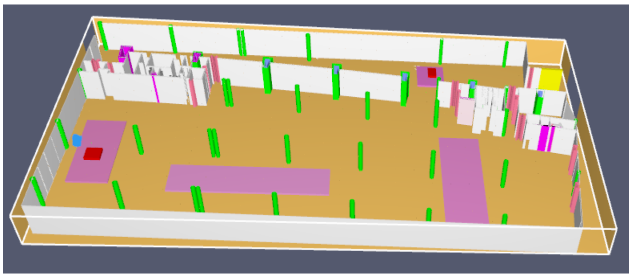

Figure 19. Startup status of automatic sprinkler fire extinguishing system at t=10s

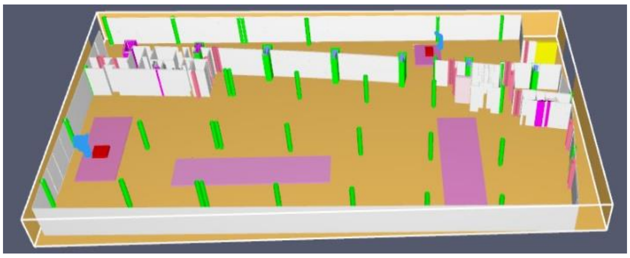

Figure 20. Starting status of an automatic sprinkler system at t = 11s

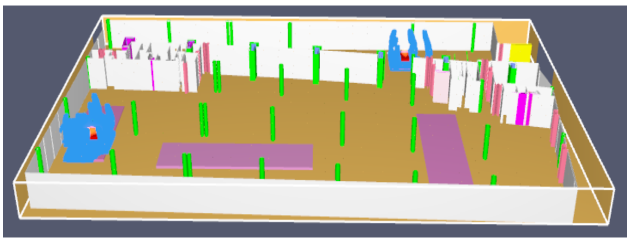

Figure 21. Starting status of automatic sprinkler system at t = 35s

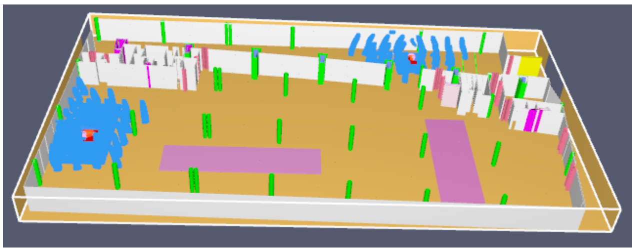

Figure 22. Starting status of an automatic sprinkler system at t = 90s

At t=181s, most of the sprinklers near the combustion points of System B respond and have a large water spray area. In addition to covering the PVC advertising decoration floor at the combustion points, it also covers the surrounding building structure, as shown in Figure 23. At t=240 s, compared with the previous moment, although the number of sprinklers in the hall and aisle started to increase slightly, the burning PVC advertisement decorated the floor, and the burning is still ongoing, as shown in Figure 24.

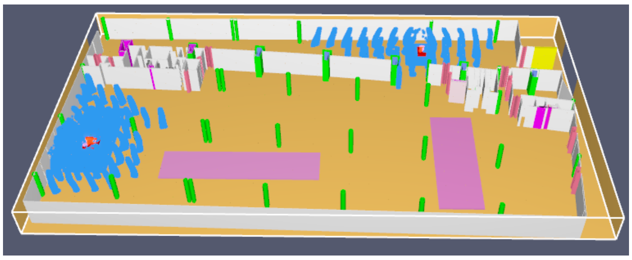

Figure 23. Starting status of automatic sprinkler system at t = 181s

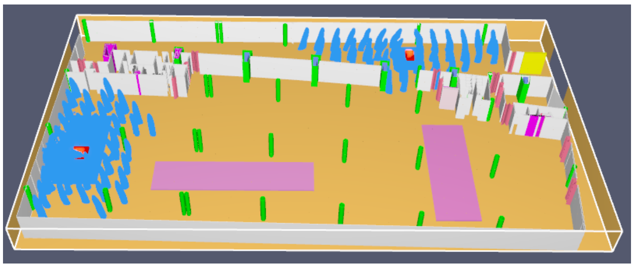

Figure 24. Starting status of an automatic sprinkler system at t = 240s

3.3.3 Comparison and analysis of system A and system B

According to the above discussion and analysis, the response speed of System B is faster than that of System A, and the time required for the nozzle first to respond is shorter. However, as time goes by, the number of starting heads of System A gradually exceeds that of System B, and in the fourth minute, the water spraying area of System A is larger. On the one hand, this may be due to the smaller nozzle spacing of System B, the stronger inhibition of the combustion heat release, and the slower temperature rise; thus, the temperature near the fire source is lower, and the response number is less; on the other hand, the System B is denser, and the heat temperature flue gas cooling effect is stronger, the heat dissipation is larger and the fire temperature is relatively lower, resulting in the response of System A is more, and the injection area is larger. In general, with continuous combustion, the response degree of the automatic sprinkler system is constantly improved, the number of starting heads is more and more, and the protection area of the system is also larger and larger. To some extent, the automatic sprinkler system is beneficial in protecting the space around the fire site and preventing the spread of the fire. However, in this model, due to the high combustion calorific value of the PVC advertising decoration floor and the intense response, the temperature in the central area of the fire has been high, so it cannot be completely extinguished by the automatic sprinkler system. However, the PVC advertisement decorated the floor, even if it was very close to the burning point, but within 4 minutes, it was ignited, and the automatic sprinkler system played a very important role.

4. Conclusion

(1) Smoke in the early stages of the fire site spreads very quickly. In just a few minutes, the fire smoke can spread to the whole model, resulting in reduced visibility of the fire, which is not conducive to escape. Therefore, attention should be paid to the design of smoke prevention and exhaust in public places with a high density of people, effectively inhibiting the diffusion of smoke and giving people more time to escape.

(2) The environmental temperature of the fire site changes rapidly. The ambient temperature near the fire source can quickly break through 100°C, causing serious damage to the surrounding personnel. Therefore, when choosing the escape channel, you should try to choose the route far away from the center of the fire source. If each route is filled with high-temperature smoke, you should crawl forward to avoid being burned and scalded by the high-temperature smoke.

(3) An automatic sprinkler system is conducive to restraining the expansion of the fire and facilitating the evacuation of personnel. An automatic sprinkler system can effectively reduce the temperature of the fire smoke to prevent evacuating pedestrians due to high temperatures or igniting other combustibles, resulting in the control of fire. In addition, equipped with higher specifications of automatic sprinkler systems can further buy valuable time for personnel to escape.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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