

Retraction

Retracted: Simulation Study on Fire Visibility of Typical Floor Planes of Modern Super High-Rise Office Buildings in China

Complexity

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

- [1] T. Zhang, "Simulation Study on Fire Visibility of Typical Floor Planes of Modern Super High-Rise Office Buildings in China," *Complexity*, vol. 2020, Article ID 8868522, 14 pages, 2020.

Research Article

Simulation Study on Fire Visibility of Typical Floor Planes of Modern Super High-Rise Office Buildings in China

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With the development of office forms, the space form of super high-rise office buildings changed from the unitary efficient office space to a complex space that integrated office, communication, and experience, which also diversified the design of typical floors in the office zone. However, from the perspective of fire prevention, the placement of shared space changed the form of the plane in typical floors in the office zone, affecting the smoke spreading of fire and paths of personnel evacuation. Hence, the subject on the planar relationship among high-rise office buildings based on fire prevention analysis, which optimizes space design, is worthy of discussion. After collecting many cases of super high-rise office buildings in China, this study categorized them into six typical planes and adopted the software PyroSim for comparative simulation of the smoke spreading of fire. By comparing the visibility of different zones in fires, this study analyzed the effects of the area of the office zone, the location of the atrium, and the form of the plane on the fire visibility on the typical floor and put forth the key factors that influence fire visibility, thus optimizing the plane design of the typical floor of super high-rise buildings. The findings show that in the six fire scenes, the area of the office zone is between 1136m^2 and 1736m^2 . The peak of duration for visibility decline at 1.5 m appeared in Scene 3. Its office zone is 1536m^2 , and the duration of visibility decline is greater than 1000 s. In other fire scenes, the duration of visibility decline is less than 300 s. By comparing the plane arrangement features of the fire scenes, the paper concludes that in a given fire scene, establishing an atrium in the office zone, expanding the length of the adjacent edge between the atrium and the office zone, and building an evacuation corridor between the atrium and the core tube can greatly extend the effective evacuation time. This can serve as reference for the plane design of super high-rise office buildings.

1. Introduction

Super high-rise office buildings shoulder the important mission of multilayered optimization and development. Advancements in structural engineering have arisen to make possible the increase in height size and complexity, the reduction of cost and carbon footprint, and architectural imagination and economic versatility of these buildings [1]. As the modern office model becomes increasingly integrated, open, and smart, the plane design of typical floors, on the one hand, has increased the utilization value of the building space. But on the other hand, it has caused new fire safety problems to the buildings and resulted in greater difficulty in the fire safety design of the typical floor of buildings (Torero et al. [2]).

From both functional and structural perspectives, the typical floor plane of super high-rise office buildings, in general, can be roughly divided into two parts—the service part featuring core tubes and the service-receiving part characterized by frameworks. Judging from the development trend of existing structural techniques and the area of the typical floor, the upper limit of the ideal area of a typical floor can be lifted to 4000m^2 in a predictable future. After analyzing and investigating into the plane design drawings of super high-rise office buildings in recent years, this study has found that the floor space of an open and integrated office model needs to be as large as possible and continuous. Maximizing the plane area of the typical floor and exploring open office compartments are the two trends in the plane design of these buildings in modern times. For an office

space, a greater pillar spacing provides a broader view. As a design principle followed by the buildings of this kind in modern times, the pillar-free design indicates that in a designated office space, all bearing pillars are located near the curtain walls on all sides of the space to create a pillar-free space to provide a more flexible and efficient office zone. The correct definition of the design fire for open plan compartments is identified as the critical knowledge gap that must be addressed in order to achieve tall building performance objectives and to provide truly innovative, robust fire safety for these unique structures [1].

We have seen how classic prescriptive solutions failed to manage smoke (Cook Country Building (USA) [3] and Camberwell fire (UK)) [4] and how modern buildings using state-of-the-art fire engineering failed to contain the full propagation of a fire (TVCC, China) [5]. Analyses of several failures and current design practices reveal that fire safety codes are no longer capable of providing implicit safety for the rapidly evolving needs of modern tall buildings and are being extensively substituted by nonvalidated performance-based design methods [1, 6]. Therefore, how to maximize the office zone on the typical floor and the space utilization efficiency while meeting the technical requirements on fire safety is a difficulty in typical floor design (Xing et al. [7]).

1.1. Fire Load of Super High-Rise Office Buildings. Usually, massive office equipment, materials, papers, and archives are placed in an office. All these are highly combustible objects, thus imposing a heavy fire load on the office zone. Fire load (Q_f) refers to both the heat of combustion of all combustible objects in the office zone and within the regional space. It is directly proportional to fire risks and the difficulty of firefighting (Yao et al. [8]). The total fire load of a unit area is fire load density (q), which shows the severity of fire. Table 1 demonstrates the statistics on the average levels of fire load density in various functional space types of accredited buildings.

The computational analysis of the fire growth model effectively controlled smoke spread and emission. t^2 model, MRFC model, and FFB model are the mathematical models of fire growth [10]. According to the results of numerous experiments and experience, the t^2 model is used to describe the early stages of fire development in a specific space. Equation (1) is according to NFPA204M (2002):

$$Q_f = \alpha t^2, \quad (1)$$

where Q_f is the heat release rate(HRR), kW, and α is the fire increasing modulus, kW/s².

Table 2 shows the t^2 model of different fire growth coefficients (α) adopted by various building designs and the maximum heat release rate and time of different materials.

1.2. Smoke Discharge of Office Zone in Super High-Rise Buildings. According to the plane features and development trend of super high-rise office buildings, the demand for a pillar-free, open space has exceeded the maximum for a fire safety zone as required in the standards, which makes it

TABLE 1: Fire load density of different types of buildings [9].

	Space function	Density of combustible material
Office	General	30
	Design	50
	Administration	60
	Research	60

impossible to achieve the fire safety zoning according to the traditional fire safety design. A higher office zone has a higher wind speed which will accelerate fire spreading on the typical floor in case of fire. Worse still, the absence of division in the interior lateral space would speed up the spreading of smoke [11].

According to the Code for Fire Protection Design of Building (GB50016-2014), "Mechanical smoke exhaust facilities should be installed and sites with interior net story height less than 6 m should include smoke control zones; the area of structure in each smoke control zone should not exceed 500 m²; and the smoke control zone should not cross beyond the fire protection zone. The smoke control zone should be separated by structural beams of partitions and ceilings with downward bulges no less than 500 m, or incombustible components of ceilings and canopies with downward bulges no less than 500 m." The smoke exhaust volume of mechanical smoke exhaust devices is demonstrated in Table 3.

Hence, it can be concluded that the area (S) of each outlet is obtained with the following equation:

$$S = \frac{S1 \times 60 \text{ m}^3/\text{h}}{n \times 3600 \times 5 \text{ m/s}}, \quad (2)$$

where S is the area of the smoke discharge outlet, $S1$ is the area of the smoke safety zone, and n is the number of smoke discharge outlets.

The area (s) of each outlet was calculated according to the volume of the atrium through the following equation:

$$S = \frac{V \times 6}{n \times 3600 \times 10 \text{ m/s}}, \quad (3)$$

where S the area of the smoke discharge outlet, V is the volume of the atrium, and n is the number of smoke discharge outlets.

1.3. Crowd Evacuation of Super High-Rise Buildings. Crowd evacuation in super high-rise buildings is a major safety concern [12]. According to the standards (GB50016-2014), the typical floor must provide two evacuation routes in case of fire, so that those trapped in fire can take the other if either of the routes is blocked (Wang and Liu [13]). For a more spacious typical floor, evacuation routes are longer present, and the choice of routes is blurrier, which would affect evacuation (Rodrigo and Marshall [14]). A subsafety zone can be established in the atrium to alleviate the pressure of evacuation (Liu [15]). But, the fire danger of the atrium is special, so if the subsafety zone is established in an inappropriate way, it will not reduce the pressure of evacuation and will even accelerate the vertical spreading of smoke.

TABLE 2: Fire growth coefficient (NFPA204M(2002)).

Fire categories	α (kW/s ²)	Q_f = the time of 1000 kW/s	Functions
Slow fire	0.0029	600	Art gallery
Medium fire	0.012	300	Dwelling, apartment, construction room, hotel reception, hotel bedroom
Fast fire	0.047	145	Store
Superfast fire	0.187	75	—

TABLE 3: Minimum smoke exhaust volume of the mechanical system.

Conditions and parts	Unit smoke exhaust volume (m ³ (h))	Ventilation (time/h)	Notes
One section of smoke control zone	60	—	The smoke exhaust volume of each draught fan should not be less than 7200 m ³ /h
Areas with no smoke control zone and interior net story height greater than 6m			
Two or more smoke control zones	120	—	Determined according to the maximum area of smoke control zone
Atrium	Volume less than or equal to 17000 m ³	—	Volume greater than 17000 m ³ , smoke exhaust volume should be no less than 102000 m ³ /h
	Volume greater than 17000 m ³	6	
		4	

Compared with CO mass fraction and temperature, visibility was a more influential factor in determining the critical time required for fire to become a hazard, and smoke affected the adjacent open area in approximately 60 s [12]. When a fire hazard is occurring, office zone visibility can directly affect the velocity of walking. In the irritating state and nonirritating state, the velocity of walking declines as the obscuration coefficient increases. In the irritating state, the velocity of walking showed sudden decline. Hence, the visibility of the horizontal section (1.5 m of interface) at the height of sight of crowd evacuation is one of the effective evaluation criteria about whether a certain area fits the condition of evacuation. In simulated calculations, the critical time of a dangerous situation is time T_4 for visibility to decline to 10 m [16].

2. Materials and Methods

This research uses the software PyroSim to simulate the smoke spreading of fire [17]. The simulation process includes the following steps: (1) Building geometric models; (2) Establishing fire scenarios, including location and load of combustion source, simulation scope and boundary condition, different types of combustible materials, performance of firefighting equipment, duration and accuracy of simulation; and (3) conducting simulated calculation through FDS/smokeview for posttreatment of results [18]. In this process, by building the models, the simulation results could indicate the distribution graph of visibility of fire smoke in the model [19].

2.1. Establishment of an Abstract Model. After the investigation and the analysis of the existing super high-rise office buildings in China, this study confined the research subjects to those with a height of at least 150 m, a typical floor plane

of less than 3,000 m², and a tube-in-tube structure. To carry out a comparative simulation experiment, the plane prototype of the typical floor of an office building was made. The plane was a 45 m × 45 m square plane, with an area of 2,475 m². In the center of the plane was a 17 m × 17 m core tube. The space beyond the core tube was an integrated office area of 2,186 m², whose story height was 4.2 meters and net height was 2.9 meters.

In most of the super high-rise office building designs, the atrium is the primary spatial element of plane design. The position and form of atrium is the main factor leading to different typical floor planes. Hence, by incorporating an atrium into the plane prototype, it can be deformed and derived. The approach and logic of incorporating the atrium have two aspects worth discussion: (1) In a fire hazard, the impact of the atrium area on visibility of the office zone; (2) in a fire hazard, the influence of position of atrium space in the office floor plane on visibility of office space. Responding to the above questions, (3) by gradually increasing the area of the atrium in the plane prototype, the derivative plane is obtained, which is shown in Figure 1. (4) By changing the position of the atrium in the plane prototype, the derivative plane is obtained, which is shown in Figure 2. Lastly, six typical floor planes (plane A–plane F) are concluded to serve as the typical floors and planes in this research.

In the above six typical planes, other than the core tube, all areas of plane A are the office zone, which is distributed in the way similar to the character shape “回.” It has the highest efficiency and stable structure for office utilization. However, due to the excessive spatial continuity, the horizontal smoke spreading rate is rather high. There is no atrium space to contain the excessive depth of the office zone, so the smoke exhaust efficiency is low, and crowd evacuation is difficult to be carried out. In plane B/C, plane D, and plane E/F, when the atrium space ratio increased, the office zone area decreased, and the smoke exhaust efficiency increased as well.

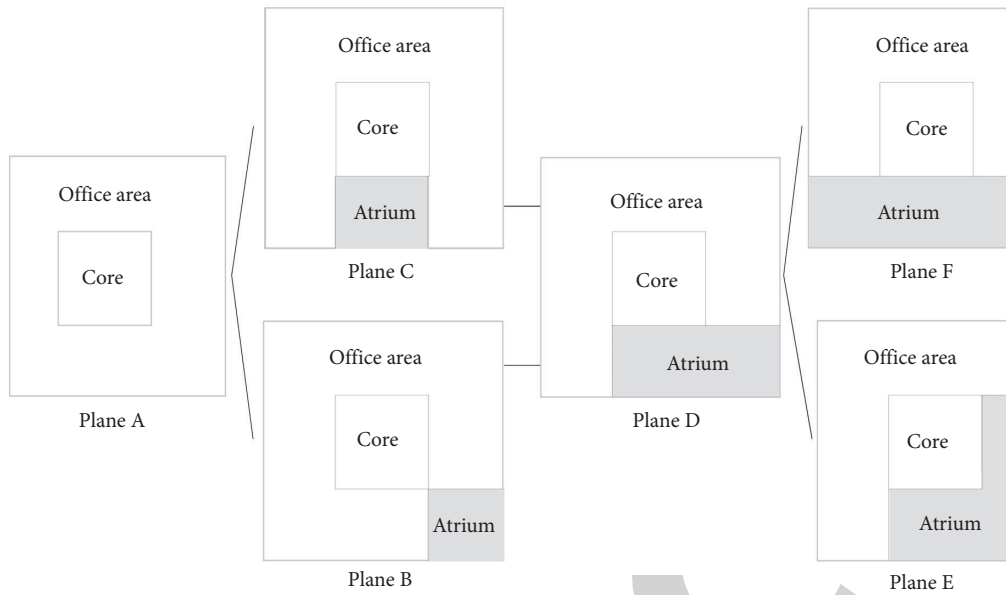


FIGURE 1: Different area proportions of the same atrium position in the plane prototype.

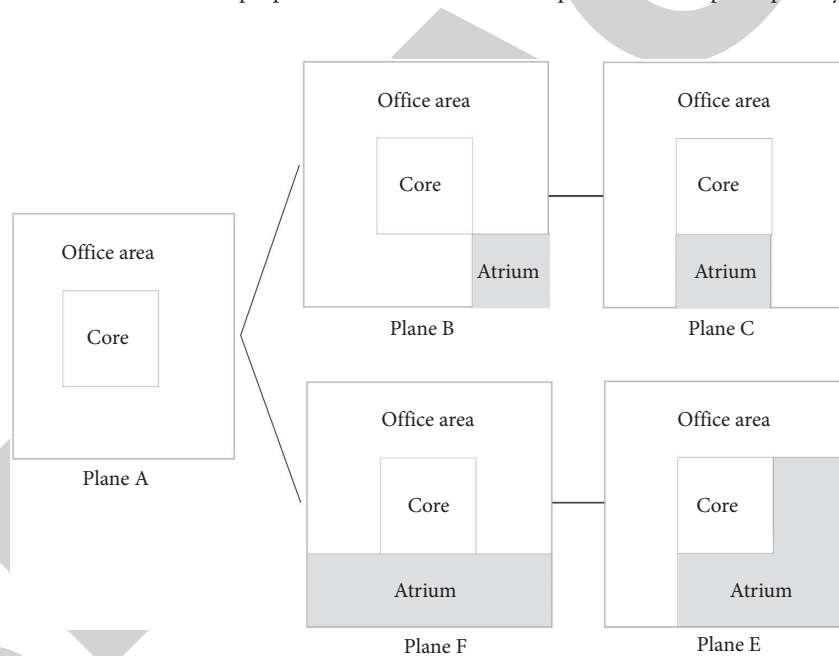


FIGURE 2: Different positions of the same atrium area in the plane prototype.

However, when the area of the office zone became smaller, the time for smoke to sink declines, which may negatively influence visibility. Moreover, smaller office zone reduced the service efficiency and structural stability of buildings. Plane B/C and plane E/F are the typical floor planes with the same atrium area. The atrium positions of the two planes are, respectively, in the single-sided area and corner area of the “回”-shaped office zone. It significantly improved the plane modality of the office area and affected the routes of smoke

spreading. The contrast and analysis of plane features of the six typical floors are shown in Table 4.

In the comparative simulation experience, a piece of virtual land was chosen for a single super high-rise building with a $45\text{ m} \times 45\text{ m}$ base. The six typical planes were modeled according to the same rules, and their planes were initially designed according to the existing standards to ensure that all the six buildings were a super high-rise office building 294 m high. Besides, there was no atrium in Model A, while

TABLE 4: Contrast of spatial elements in the six typical floor planes.

Typical planes	Plane A	Plane B	Plane C	Plane D	Plane E	Plane F
Atrium area ratio	0	1/9	1/9	2/9	1/3	1/3
Atrium position	—	Corner area	Single-sided area	—	Corner area	Single-sided area
Inner side of the atrium	—	2 planes	3 planes	3 planes	4 planes	3 planes
Utilization efficiency of office space		High		Medium		Low

there was a 42 meter-high atrium for every ten floors in Models B to F. The comparative models are shown in Figure 3, where light pink indicates the scope of simulation and dark red represents the floor with fire. Geometric models of simulation scope are shown in Figure 4.

2.2. Design of Fire Scenes. According to the standards, geometric models were established based on the hypothesized comparative simulation schemes, and the fire scenes were designed. In all the six fire scenes, the t^2 fire was regarded as the source of fire, and the heat release rate was medium.

To ensure that people on the typical floor of super high-rise office buildings could evacuate in two different directions, the planes were optimized in the geometric model designs: a 2-meter-wide corridor was created adjacent to the core tube for the two office areas separated by the atrium in the planes equipped with an atrium, so that the office areas always encircle the core tube. As the whole typical floor was an integrated office space, the office area was not furnished with a fire shield. However, the fire shield was utilized to separate the atrium from the office area, and the atrium was established as a separate fire safety zone. An adequate number of smoke safety zones were established in all the six scenes. The largest smoke safety zone was 434 m², smaller than the maximum of 500 m² as specified in the standards. The height of all the antismoke boards was 0.6 m, higher than the maximum of 0.5 m as specified in the standards.

As for the layout of the firefighting facilities, the sensing temperature of all the automatic sprinklers was 68°C, and the wind speed of the smoke discharge outlets was 5 m/s, and the outlets would stop working if the temperature reached 280°C. At least two smoke discharge outlets were installed in each smoke safety zone in the office area, and the distance between outlets was shorter than 60 m. The specification of smoke discharge outlet was determined according to the area of the smoke safety zone. According to previously mentioned standard requirements and formulas, ten 0.6 m × 0.9 m outlets were installed. The lower parts around the office area were equipped with five air supplies, and the wind speed was 5 m/s. Besides, the air supply amount met the minimum value (no less than 50% of smoke discharge amount) as specified in the national standards. In the atrium area, the atrium worked as a separate fire safety zone. As the height of the atrium was over 12 meters, the mechanical smoke discharge was adopted. All the smoke discharge outlets were installed on the top of the atrium and on the sides of each structural floor. Smoke shields were installed between the atrium and the office area and would be shut 30 s after the smoke alarm went off. A hole sharing the same

size with mesh was used to simulate a crack. A controlling device was installed on the curtain wall closest to the burner. If the temperature reached 500°C (flash burning), the window would be broken (vanish). Horizontal slices were installed 1.5 m above the ground to collect data of visibility [20].

The floor plans of the geometric models and the firefighting facilities are shown in Figure 5. The parameters of each fire scene are shown in Table 5.

3. Results and Discussion

Multiple slices were installed for measurement. Holes sharing the same size with a mesh cell were distributed evenly around the model to simulate the cracks between a normal curtain wall and the floor slab and simulate a real scene. A comparative experiment on the six models was carried out. In a fire, the basic logic of smoke control was as follows. In Models A to F, the burner started to burn from second 0, and the first sprinkler was initiated at a different time, and the HRR curve was kept constant; at this moment, the fire continued to burn but stopped spreading (for specific data, see Figure 6). After the first smoke alarm was initiated, the exhaust system was initiated, and the smoke shield was shut 30 seconds later. In Models B to F, thermocouples were placed near the window closest to the burner and beside the glass in the atrium garden. The controlling device was installed, and when the temperature reached 500°C (flash burning), the window would be broken (vanished). None of the Models B to F reached 500°C.

3.1. Results of Visibility Simulation. Sections at different temporal points of the horizontal plane 1.5 m (average practical height) above the ground were taken to observe the changes of the visibility graph, in order to obtain the results of simulation in six fire scenes (Table 6).

The results of visibility simulation show the change to visibility of all the typical planes under the same fire condition. ① In Fire Scene 1, there was no atrium, and the office area encircled the core tube. In a fire, the visibility in the fire safety zone of the fire source was reduced to below 10 m 120 s after the fire started. Then, smoke spread to both sides at the same time, and the visibility of two adjacent fire safety zones began to decline and then went down to less than 10 m 174 s after the fire started. When the smoke spread for 230 s, the visibility of the whole office area was less than 10 m. ② In Fire Scene 2, there was an atrium on the typical floor. As the atrium was located at one corner of the plane, the core tube was still encircled by the office area. In a fire, the visibility in the fire safety zone of the fire source declined to less than

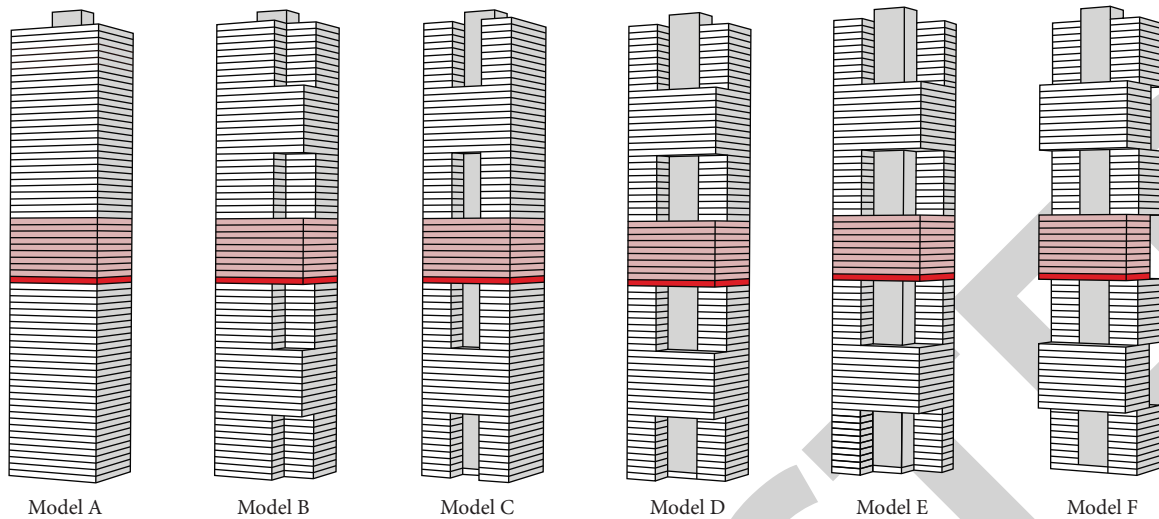


FIGURE 3: Architectural models of the typical planes.

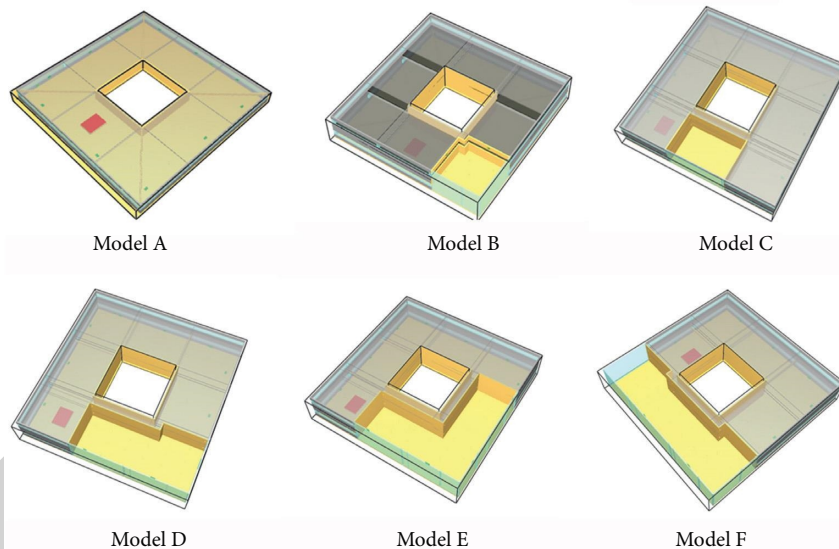


FIGURE 4: Geometric models.

10 m 96 s after the fire started. Then, smoke spread to both sides at the same time. As the size of two openings between the fire area and the two adjacent areas was different, there was a noticeable asymmetric distribution of the reduction rates of visibility: the visibility of the area with the larger opening was reduced significantly, while that with the smaller opening dropped slower. When the smoke spread for 255 s, the visibility of the whole office area was less than 10 m. ③ In Fire Scene 3, there was an atrium on the typical floor. The atrium covered one-fourth of the circumference of the core tube, and the office area covered three-fourths of the circumference. In a fire, the visibility in the fire safety zone of the fire source was reduced to less than 10 m 78 s after the fire started. Then, smoke spread to both sides at the same time. As the size of two openings between the fire area and the two adjacent areas was different, there was a noticeable

asymmetric distribution of the reduction rates of visibility: the visibility of the area with the larger opening was reduced significantly, while that with the smaller opening dropped slower; besides, a visual corridor with high visibility was formed between the atrium and the core tube. The visibility of the whole office zone was below 10 m 1000 s after the fire started. ④ Fire Scene 4 had a similar process of visibility reduction with Fire Scene 3. The atrium still covered one-fourth of the circumference of the core tube. But, as the atrium area was larger and the office area was smaller in Fire Scene 4 than Fire Scene 3, it took a shorter time (260 s) for the visibility of Fire Scene 4 to drop to less than 10 m. ⑤ In Fire Scene 5, the atrium on the typical floor continued to become larger, and the office area continued to shrink to 1,136 m², and both the atrium and the office area covered half of the circumference of the core tube, respectively. In a

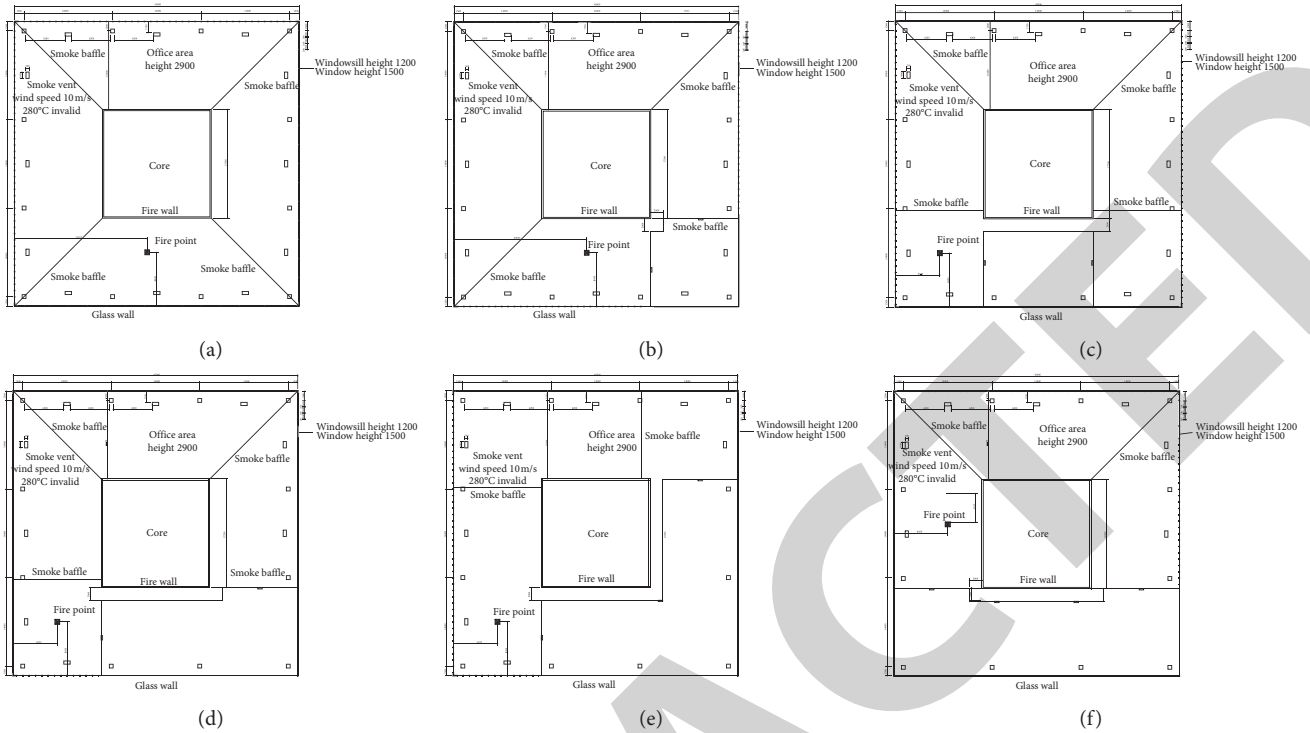


FIGURE 5: Floor plans of the comparative models.

TABLE 5: Parameters of the fire scene design.

	A	B	C	D	E	F
Office area (m ²)	1736	1536	1536	1336	1136	1136
Atrium area (m ²)	0	200	200	400	600	600
The amount of smoke discharged from the office area (m ³ /s)	28.9	25.6	25.6	22.3	22.3	22.3
The amount of smoke discharged from the atrium area (m ³ /s)	0	4	4	7	10	10
Height of smoke shield (mm)	600					
Fuel type	Built-in POLYURETHANE-PyroSim $C = 6.3$, $H = 7.1$, $O = 2.1$, and $N = 1.0$; common data for simulating office fire					
Soot yield, y	0.07 kg/kg fuel					
CO yield, y_{CO}	0.04 kg/kg fuel					
Heat of combustion, ΔH_c	1.3×10^4 kJ/kg, O ₂					
Radioactive fraction	35%					
Burner height (mm)	500					
Fire growth rate	$Q = 0.017 t^2$ medium fire					
HRRPUA	1000 kw/m ² (FDS), burner size of 5 m × 4 m					
Peak heat release rate	20 MW or HRR controlled by spray					
Fire sprinkler	Standard sprinkler head: RTI 135, temperature 68°C, C factor -0.85, spacing of 3.6 m, referring to the Chinese standard for office					
Smoke detection parameters	Photoelectric type, spacing 5.8 m, referring to Chinese standard.					

fire, the visibility in the fire safety zone of the fire source was reduced to less than 10 m 85 s after the fire started. As the size of two openings between the fire area and the two adjacent areas was different, there was a noticeable asymmetric distribution of the reduction rates of visibility: the visibility of the area with the larger opening was reduced significantly, while that with the smaller opening dropped slower; besides, a visual corridor with high visibility was formed between the atrium and the core tube. When the smoke spread for 230 s, the visibility of the whole office area was less than 10 m. © Fire Scene 6 shared the same area of

the office zone (1,136 m²) with Fire Scene 5. The atrium took the shape of “—,” covering one-fourth of the circumference of the core tube. In a fire, the visibility in the fire safety zone of the fire source was reduced to less than 10 m 85 s after the fire started. As the size of two openings between the fire area and the two adjacent areas was different, there was a noticeable asymmetric distribution of the reduction rates of visibility: the visibility of the area with the larger opening was reduced significantly, while that with the smaller opening dropped slower; besides, a visual corridor with high visibility was formed between the atrium and the core tube. When the

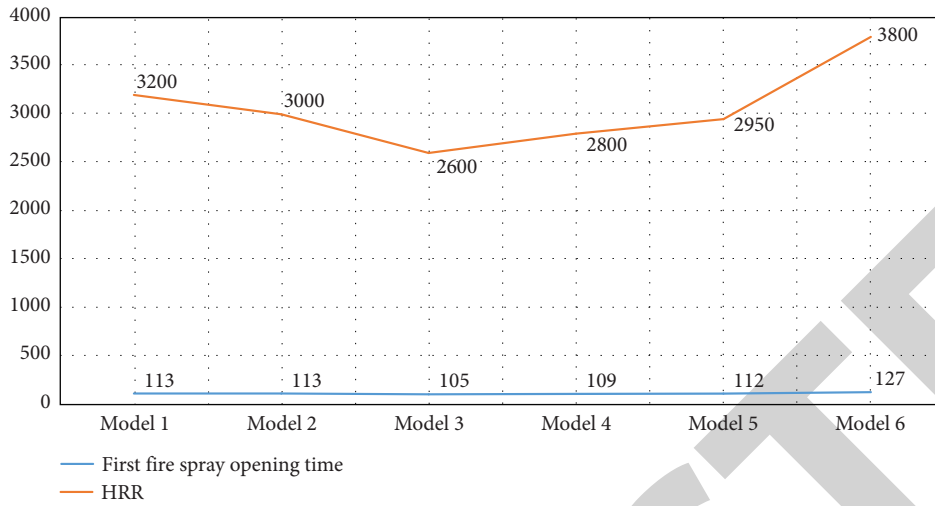


FIGURE 6: Comparison of data about smoke control.

TABLE 6: Visibility distribution graph of different temporal points in six fire scenes.

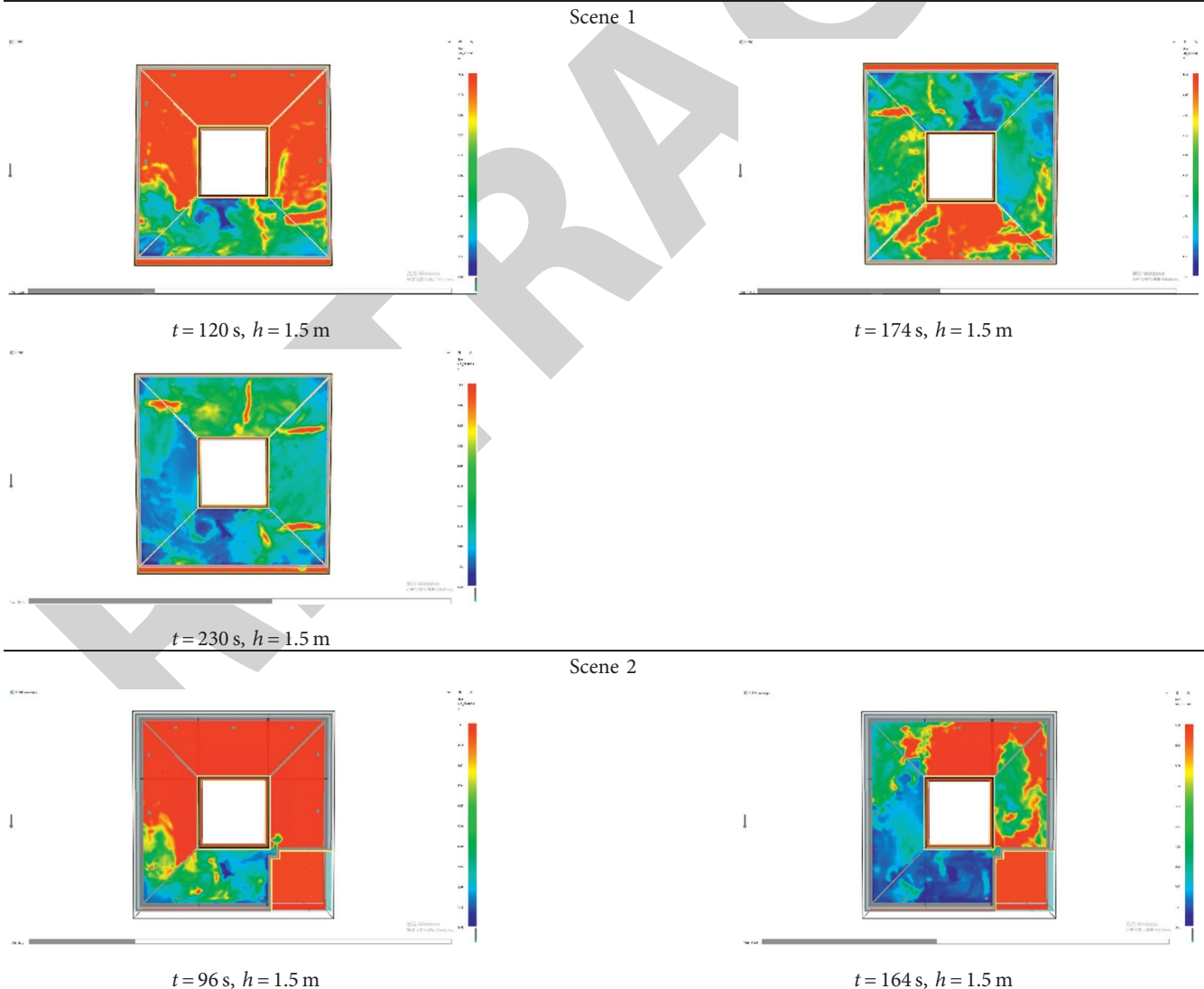


TABLE 6: Continued.

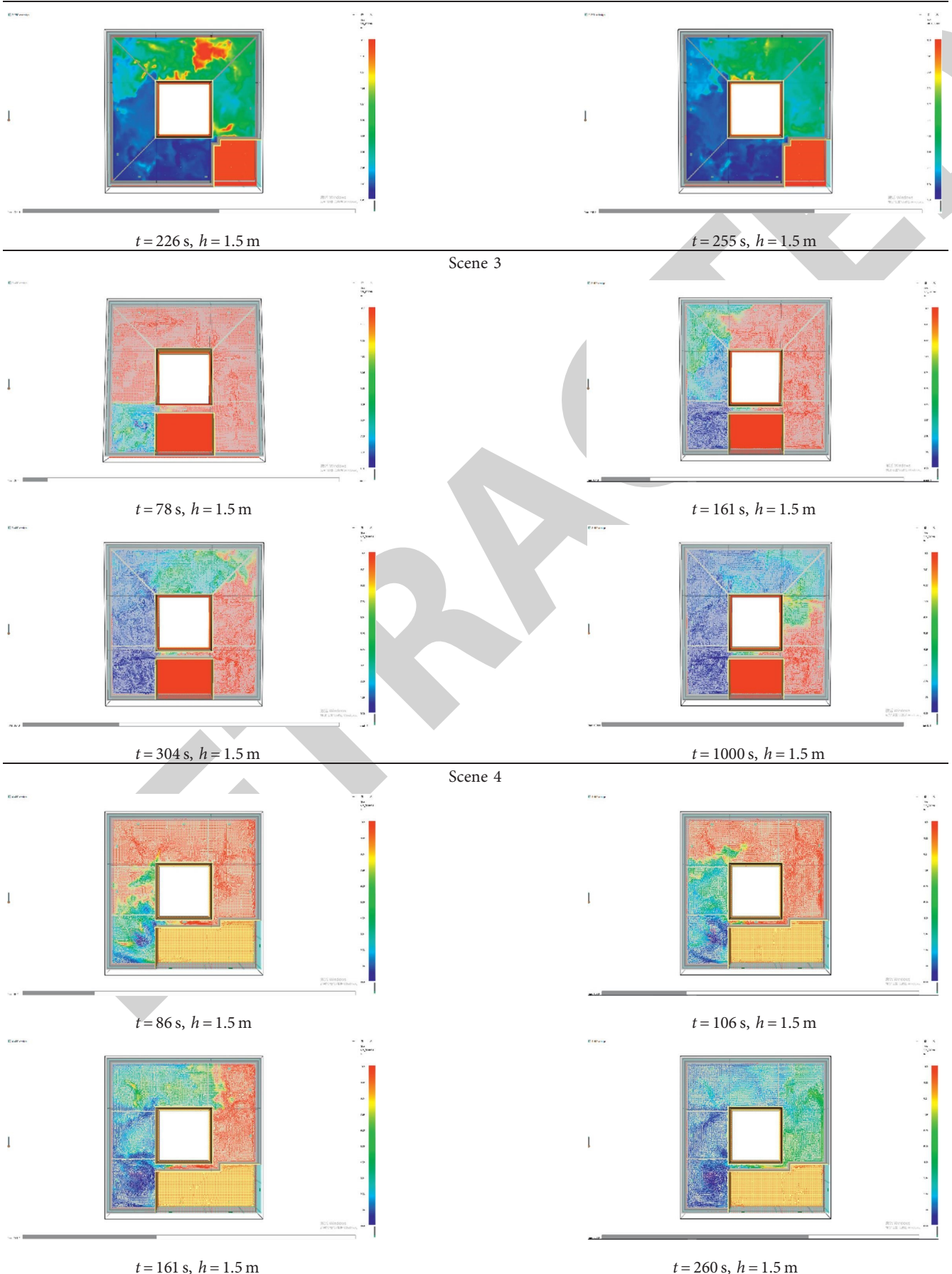
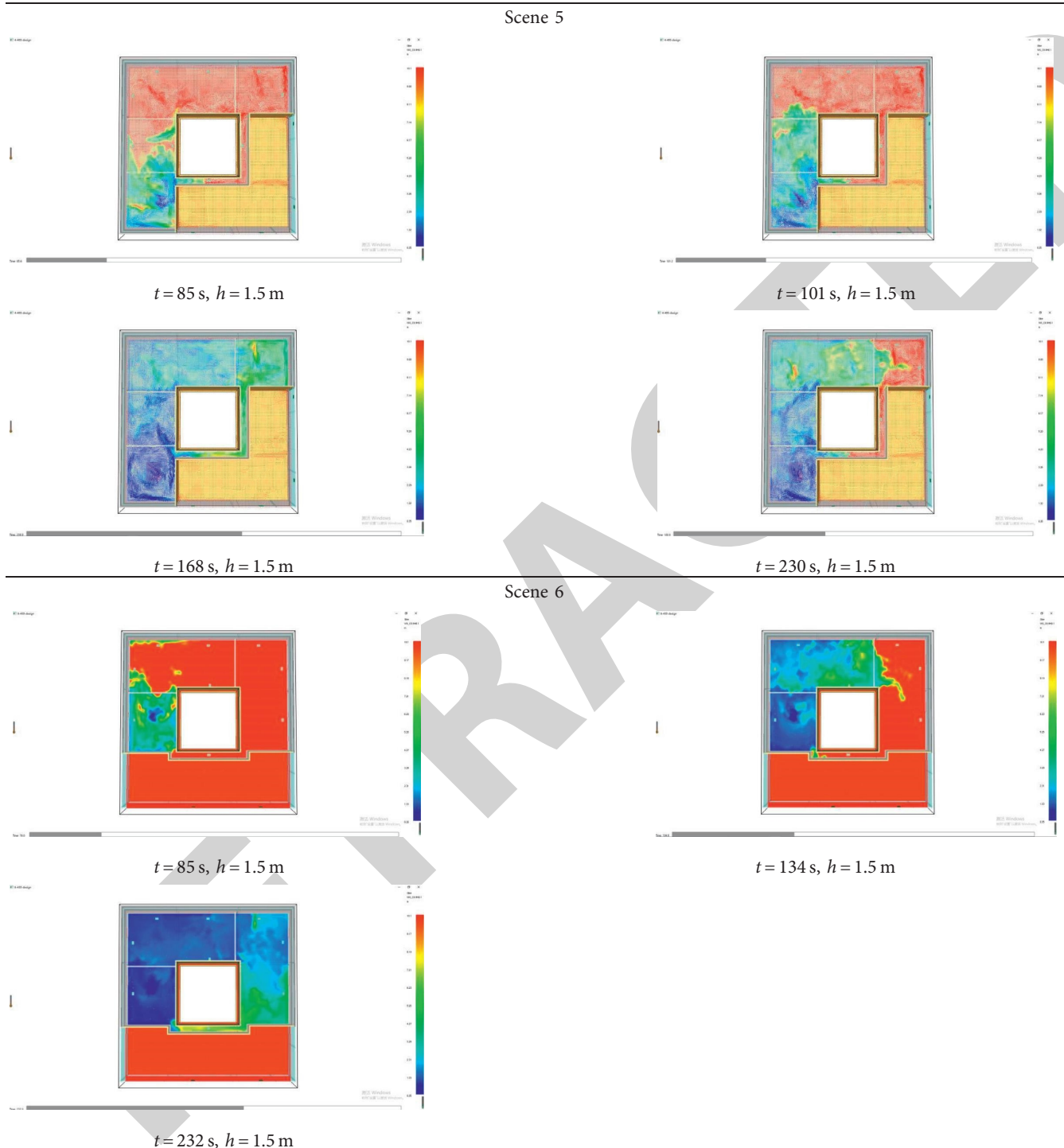


TABLE 6: Continued.



smoke spread for 232 s, the visibility of the whole office area was less than 10 m.

3.2. Visibility Comparison Analysis

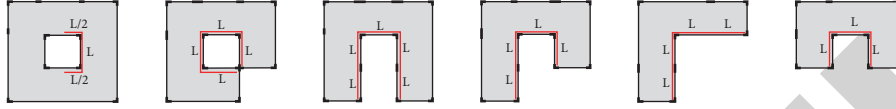
3.2.1. Overall Visibility Comparison Analysis. When the area of the typical floor and the height of the floor remained

unchanged, the area (volume) of the office zone gradually became smaller with the increasing single-floor area of the atrium from Fire Scene 1 to Fire Scene 6, but the time for the visibility to drop to 1.5 m due to the spreading of smoke did not show any sign of becoming shorter. The duration of visibility reduction reached a peak value in Fire Scene 3. In other words, when the office area was $1,536 \text{ m}^2$ and the atrium was established on one side of the core tube, the

TABLE 7: Comparison of visibility data among different fire scenes.

	Scene 1	Scene 2	Scene 3	Scene 4	Scene 5	Scene 6
Office area (m ²)	1736	1536	1536	1336	1136	1136
Smoke spreading path	2L	4L	5L	4L	4L	3L
Duration of overall visibility reduction	230 s	226 s	>1000 s	260 s	230 s	232 s

Plane shape



duration of visibility reduction was the longest. Under other circumstances, the area (volume) of the office zone, the area of the atrium, and the location of the atrium all had influence on the duration of overall visibility reduction of the office area. Therefore, a comparative research on the six models under two circumstances “when the area (volume) of the office zone was different” and “when the area (volume) of the office zone was the same but the location of the atrium was different” was carried out.

- (1) When the area (volume) of the office zone was different but the location of the atrium was the same.

In the comparison among Fire Scenes 1, 2, and 4, the office area of Models A, B, and D decreased progressively with a tolerance of 200 m², and the spreading rate of smoke showed a trend of increasing progressively ($V_A > V_B > V_D$). But, as there was a great difference in the plane of the office area of the three models, there was some difference in the smoke spreading path. According to the abstract plane of the office area (Table 7), the smoke in Model A spread to both sides in a symmetric way, so its smoke spreading path was counted as “2L.” The smoke spreading path of Model B and Model D was a one-way path which was counted as “4L.” The relationship among the three smoke spreading paths of the three models was “ $L_A < L_B = L_C$.” According to the simulation results, the total duration of visibility reduction of the three fire scenes was almost the same. This demonstrates that the establishment of the atrium reduced the area of the office zone, but this improved the smoke spreading path, and a one-way smoke spreading path had greater impact on overall visibility than the area (volume) of the office zone.

- (2) When the area (volume) of the office zone was the same but the location of the atrium was different.






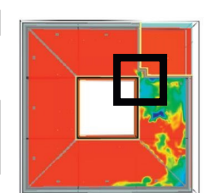
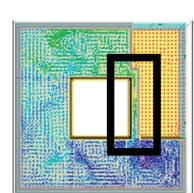
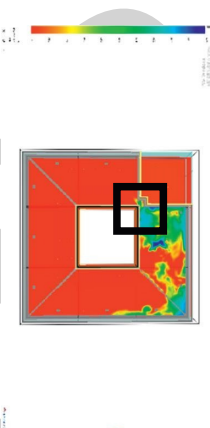
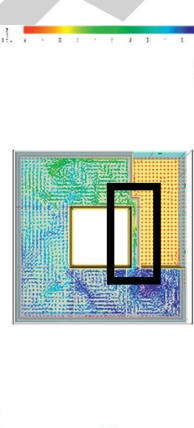
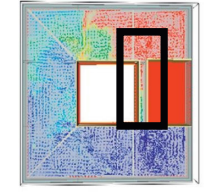
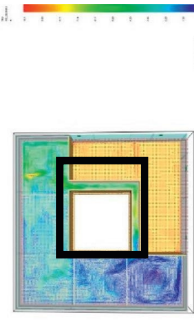
In the comparison between Fire Scene 2 and Fire Scene 3, the office area (volume) and smoke spreading rate of Models B and C were the same. According to the abstract plane of the office area (Table 7), the smoke spreading path of Model B was “4L” and that of Model C was “5L.” The simulation

results show that the duration of visibility reduction in Fire Scene 3 was remarkably longer than that in Fire Scene 2.

In the comparison between Fire Scene 5 and Fire Scene 6, the office area (volume) and smoke spreading rate of Models E and F were the same. According to the abstract plane of the office area (Table 7), the smoke spreading path of Model E was “4L” and that of Model F was “3L.” The simulation results show that the duration of visibility reduction in Fire Scene 5 was longer than that in Fire Scene 6. It is obvious that the smoke spreading path had greater influence on the overall visibility of the office than smoke spreading rate. In other words, the location of the atrium had greater influence on the duration of overall visibility reduction than the area (volume) of the office zone.

3.2.2. Corridor Visibility Comparison. According to the standards, an evacuation exit was set on one side of the office area adjacent to the atrium to ensure that each fire safety zone was equipped with two evacuation exits, and the exit must be as close to the core tube as possible. Therefore, evacuation corridors of different lengths between the atrium and the core tube were established according to different floor planes. As there was no atrium in Model A, there was no evacuation corridor. In Model B, the atrium was established at one corner of the plane, so an L-shaped corridor (represented as “L”) was formed between the atrium and the core tube. In Model C, a corridor with the length of “L” was formed between the atrium and the core tube. The two ends of the corridor were connected with two fire safety zones. In Model D, a corridor with the length of “L” was formed between the atrium and the core tube. One end of the corridor was connected with the fire safety zone, and the other end was linked with the L-shaped corner of the fire safety zone. In Model E, a corridor with the length of “2L” was formed between the atrium and the core tube. The two ends of the corridor were connected with two fire safety zones. In Model F, a corridor with the length of “L” was formed between the atrium and the core tube. One end of the corridor was connected with the fire safety zone, and the other end was linked with the L-shaped corner of the fire

TABLE 8: Comparison of overall visibility data among the fire scenes.

	Scene 1	Scene 2	Scene 3	Scene 4	Scene 5	Scene 6
Office area	1736 m ²	1536 m ²	1536 m ²	1336 m ²	1136 m ²	1136 m ²
Passage length	—	0	L	L	2L	L
Port type	—	I	0	I	0	2 I
Passage plane	—					
Duration of visibility reduction (s)	—	53 s~77 s	> 53 s~1000 s	54 s~260 s	54 s~230 s	53 s~232 s
						
	Scene 1	Scene 2	Scene 3	Scene 4	Scene 5	Scene 6

shows the corridor zone between atrium and core tube. It is also the key area leading to differences between personnel evacuation and smoke spreading.

safety zone. Table 8 shows the length and end of different evacuation corridors as well as the duration of corridor visibility reduction.

In the comparison between Fire Scene 2 and Fire Scene 4, there was no evacuation corridor in Fire Scene 2, and the two fire safety zones were connected through the corner only. In Fire Scene 4, there was an evacuation corridor with a length of “L,” and a corner was set on one end. According to the results, the visibility on one end of the corridor began to decline nearly at the same time in both fire scenes, but the duration of visibility reduction in Fire Scene 4 was noticeably longer than that in Fire Scene 2. In the comparison among Fire Scenes 3, 4, and 6, no corner was set on either end of the corridor in fire scene with the corridor length in all the three fire scenes being “L.” But, there were smoke discharge outlets in Fire Scene 3, a corner was set on one end of the corridor in Fire Scene 4, and there were corners on both ends of the corridor in Fire Scene 5. According to the results, there was marked difference in the duration of visibility reduction among the three fire scenes, and the area with a corner effectively lengthened the duration of visibility reduction on the ends of the corridor and in the corridor. Compared with a corner, a smoke discharge outlet in the corridor was more effective in slowing down the visibility reduction rate and saving more effective evacuation time for the people in the corridor.

4. Conclusion

- (1) The location of the atrium on the typical floor has a direct effect on the duration of visibility reduction.

The area (volume) of the office zone is an influencing factor to the smoke spreading rate in a fire. But, when the area of the office zone is the same or almost the same, the duration of visibility reduction in the area is, to a larger extent, influenced by the smoke spreading path. In the floor plan of a typical floor, changing the location or the plane of the atrium would effectively change the smoke spreading path in the office area. If the plane area of the typical floor is the same, more diverse and longer smoke spreading paths will lengthen the overall duration of visibility reduction on the typical floor and thus make it easier for people to evacuate.

Given the structure of super high-rise office buildings, a typical floor without atriums tends to take a symmetric form. In a fire, the smoke spreading path is the same as the evacuation path, and the fire would spread towards both ends of the fire safety zone where the fire started. This will impede evacuation. An atrium can change the smoke spreading path to ensure that the evacuation path is different from the smoke spreading path, which will facilitate the evacuation.

A longer edge shared by the atrium and the office area will lengthen the smoke spreading path and expand the duration of visibility reduction, which will lengthen the evacuation time.

In summary, establishing an atrium on the typical floor of super high-rise office buildings and lengthening the edge shared by the atrium and the office area will effectively lengthen the evacuation time in a fire.

- (2) Establishing evacuation corridors around core tubes can hinder the duration of visibility reduction.

Establishing an evacuation corridor can effectively stop smoke spreading, change the smoke spreading path in the whole office area, and effectively separate the evacuation path from the smoke spreading path. A longer evacuation corridor will lengthen the duration of visibility reduction in the evacuation corridor and will thus facilitate evacuation. Setting corners on both ends of the evacuation corridor can effectively slow down the visibility reduction on both ends and inside the evacuation corridor. But, a corner on the evacuation path would impede the evacuation and is against the design principles of an evacuation corridor. Therefore, corners are not recommended. It is suggested that smoke discharge outlets should be installed in the evacuation corridor.

Data Availability

All the data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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