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# Optimization Analysis of Mechanical Smoke Exhaust Fire Control Design in Super High Atrium of a High-rise Building

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## Abstract

**The paper analyzes the characteristics of smoke spreading in the super-high atrium of high-rise buildings and discusses the difficulties in mechanical smoke exhaust fire control design. Taking a high-rise building as an example, the mechanical smoke exhaust design of its ultra-high atrium is introduced, and solutions are put forward for its building characteristics, the location of smoke exhaust fan, the value of smoke exhaust volume and the area of the air supply outlet, and corresponding optimization strategies and specific measures are put forward, so that the proposed solution can efficiently remove smoke, achieve the safety purpose of personnel evacuation and reduce the spread of fire.**

## Keywords

**A High Level; Fire Fighting; The Atrium; Exhaust Smoke.**

## 1. Introduction

In recent years, with the improvement of architectural design level and construction technology, new buildings with spatial integration emerge in an endless stream. Oversized and ultra-high atriums make the indoor traffic lines of buildings more clear and visually more transparent, but the difficulty of smoke exhaust design brought by this has become a new subject of fire safety. In a five-star hotel in my city, a fire broke out in the atrium of a Christmas tree on two floors of about 10 meters due to the malfunction of decorative lights[1], and the whole atrium was filled with smoke within less than a minute. Therefore, the author thinks it is necessary to attach great importance to the smoke exhaust fire protection design of the atrium.

Design and deficiency of traditional atrium smoke exhaust system: In the design of high-rise building atrium smoke exhaust system, the main basis for the calculation of smoke exhaust volume is "Code for Fire Prevention Design of High-rise Civil Buildings" (GB50045-95) (2005 edition) (hereinafter referred to as "High Regulations"). According to the regulations on the exhaust air volume of the smoke exhaust system in the atrium: when the volume of the atrium is less than 17,000 m $^3$, the exhaust air volume is calculated as 6 air changes per hour of the volume; When the volume of the atrium is greater than 17000m $^3$, the smoke exhaust volume shall be calculated as 4 air changes per hour of the volume, but the minimum smoke exhaust volume shall not be less than 102000m $^3$/h. The problems of this calculation method are as follows :1) only the influence of atrium volume on smoke exhaust volume is considered, and the difference between atriums of the same volume and different heights is not considered; 2) Without considering the difference of fire loads in different atriums, the fire loads of office buildings and shopping malls are very different; 3) The smoke emission of a large volume building will be large, which is difficult to achieve in the project; 4) The irregular shape of

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the atrium has an impact on the effectiveness of smoke exhaust. In addition, there are some uncertain factors in the design of the infrared beam smoke detector started by the linkage smoke exhaust system.

## 2. Design Case Analysis

### 2.1 Project Profile

A high-rise office building is located in the total planned land area of 6,298.53 m, the total construction area of 4,1028.82 m, the building height of 97.35m. There are two floors on the ground and 24 floors on the ground. The north and south floors are divided on the ground, and the central part is connected by an atrium. The first and second floors are commercial buildings, and the above three floors are office buildings.

**Figure 1.** Architectural rendering

### 2.2 Characteristic of Project

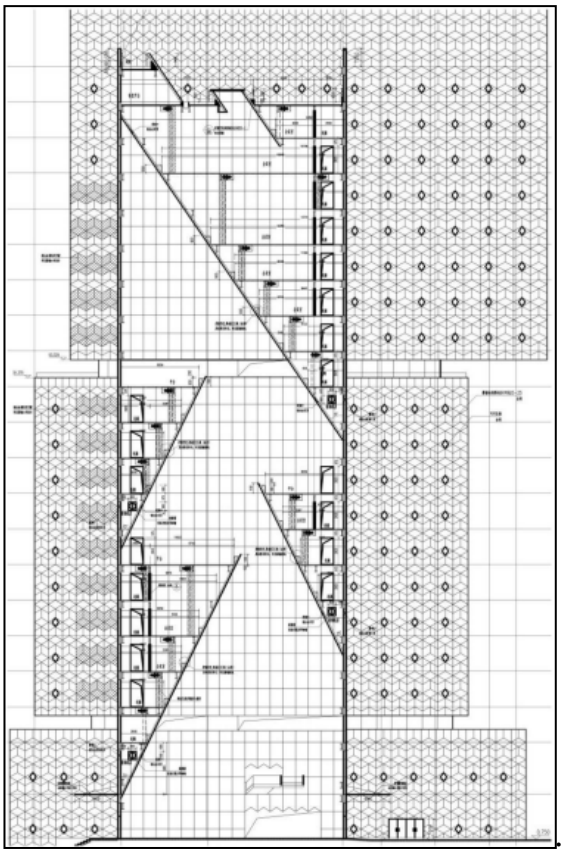

**Figure 2.** Atrium profile (Section 2-2)

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

The 8th floor, 10th floor and 13th floor are equipped with platforms connecting the office areas in the north and south areas. The atrium profile is shown in Figure 2.

The atrium of the office building is irregular in shape and high in height, so it is not easy to set smoke exhaust equipment at the top of the atrium to solve the problem of smoke prevention and exhaust. The design should consider the obstruction of smoke rising plumes or the cooling due to the smoke mixing with cold air as it rises. In the former case, the smoke may escape into the neighbourhood; In the latter case, the smoke cannot rise to the top of the atrium and form a layer of smoke at a certain height. At the same time, the fire control design should also take into account the potential of fire on the rest platform of different heights. Combined with the special architectural form of the atrium, we put forward the scheme of setting smoke exhaust facilities at different heights to effectively remove smoke from the atrium fire.

## 2.3 The Atrium Fire Smoke Exhaust Design Strategy

### 2.3.1 Fire Compartment

The building height of this project is 97.35m, belonging to the first-class high-rise building, fire resistance rating is first class. Fire zones in each area are designed according to the requirements of the code, and firewalls or fire curtains are used to divide.

The atrium runs through the first floor to the 20th floor, which is mainly separated from other areas by fire-proof rolling curtains. Fire-proof zones in the atrium include expanded front rooms on the first floor and supporting office rooms on the second floor. The other floors are mainly hollowed out areas with platforms in some parts, with a total area of 1665m2, as shown in the yellow filled areas in Fig.3 and Fig.4.

**Figure 3.** Map of fire protection zones on the first floor

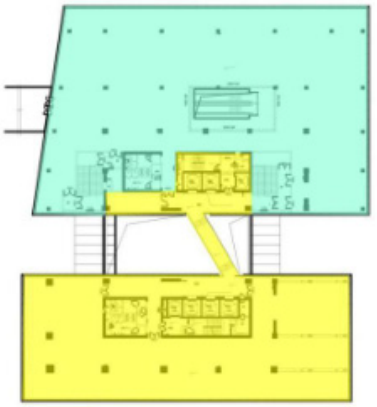

**Figure 4.** Fire protection zoning of the second floor

**Figure 5.** Three-layer fire protection zone

**Figure 6.** four-layer and above fire protection zone

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

### 2.3.2 Atrium Smoke Control Strategy

The atrium is connected from the first floor to the roof of the 20th floor, with a height of 82m. The section of the atrium changes due to the partial functional rooms on each floor. Except for the office and logistics rooms on the second floor, other areas are a smoke prevention zone, and the smoke exhaust scheme is designed as follows:

The staged smoke exhaust strategy is adopted, that is, six smoke exhaust fans are set in different elevations at the bottom of each functional room. The smoke exhaust volume of each fan is calculated separately according to the covered atrium area[2]. The distribution of smoke exhaust fans in each area is as follows:

1 exhaust fan at the top of the second floor with exhaust air volume of 15102m3/h;

1 exhaust fan at the top of the sixth floor with exhaust air volume of 22439m3/h;

1 exhaust fan at the top of the ninth floor with exhaust air volume of 17120m3/h;

1 exhaust fan at the top of the twelfth floor with exhaust air volume of 17120m3/h;

1 exhaust fan at the top of the twentieth floor with exhaust air volume of 24380m3/h;

The specific position of the exhaust fan is shown in Figure 7.

In the atrium area, the main entrance on the first floor and the louvers on the third and fourth floors are used for natural air replenishment. The area of air replenishment is 18.00m2.Linkage scheme of the atrium smoke exhaust system[3]: The number of open atrium smoke exhaust fans is programmed by the fire control center according to the site situation.

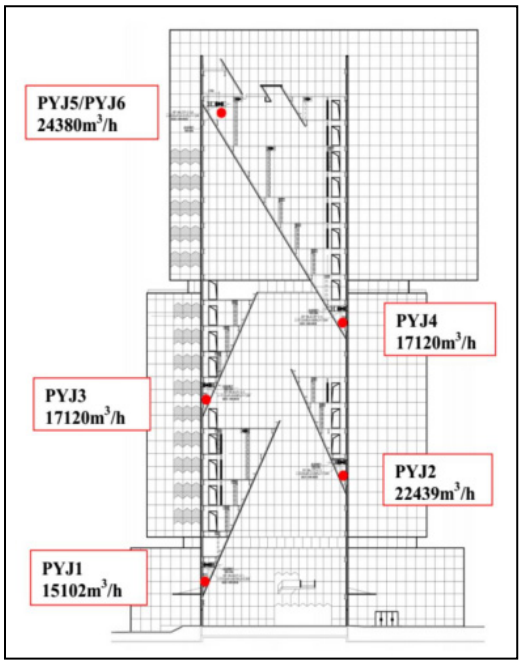


**Figure 7.** Schematic diagram of the position of exhaust fan

Since the project is complex and there is no similar building for reference, it is necessary to conduct a special model analysis on whether the smoke in the atrium can reach the position of the smoke exhaust fan after the fire (how the smoke moves in the atrium). The smoke flow of the project was simulated and analyzed, and the effectiveness of the smoke exhaust system in the atrium area was demonstrated[4].

## 3. Demonstration and Analysis of Smoke Simulation in Atrium

### 3.1 Fire Risk Analysis

In order to predict the consequences of possible fires, the site, scale and environmental conditions of possible fires should be estimated in the fire safety design. As there are infinite fire sites, sizes and

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

types of fire sources, the design of fire scenarios should be based on the characteristics of the building itself to select the "credible worst case", that is, to consider the occurrence probability and possible impact of fire scenarios.

The smoke prevention area of the atrium is mainly expanded front room on the first floor, elevator lobby on the second floor and platforms on each floor. These areas are mainly for the public flow of people, there is no combustible mass accumulation. The only possible combustibles are hand luggage, newspapers or clothes carried by people or trash cans in public areas. The fire heat release rate of these items is generally not great.The test and research data of many small fires dominated by garbage bags show that the more tightly packed garbage bags are, the higher the rate of fire combustion heat release. Generally used garbage bags, fire heat release rate size of 50kW to 300kW.

In addition, the atrium is equipped with infrared light speed detector and large space automatic water fire extinguishing device. According to NFPA92B, the height of wood flame under the scale of 1MW fire can reach 2.3m. When the fire develops to 1MW, the infrared light speed detector and automatic water extinguishing device system should have detected the fire and started to control the fire. Shanghai "Building Smoke Control and Exhaust Technical Regulations" stipulate that the fire scale of atrium under the action of spray is 1MW. Therefore, it can be considered that the credible design fire size in the atrium area under normal circumstances does not exceed 1MW fire.

## 3.2 Scene Design

### 3.2.1 Fire Scenario (NO:01)

Atrium fire scenario 1: The fire in the atrium is 1MW in the enlarged front room on the first floor, and the fire source is located under the connecting bridge on the L2 floor of the atrium [5]. This fire scenario simulates and analyzes the spread of the smoke in the atrium when the fire occurs on the first floor, under the action of the smoke exhaust fans on the second and sixth floors, other smoke exhaust fans send alarm signals after detecting the smoke according to the infrared beam detector and then start in linkage.

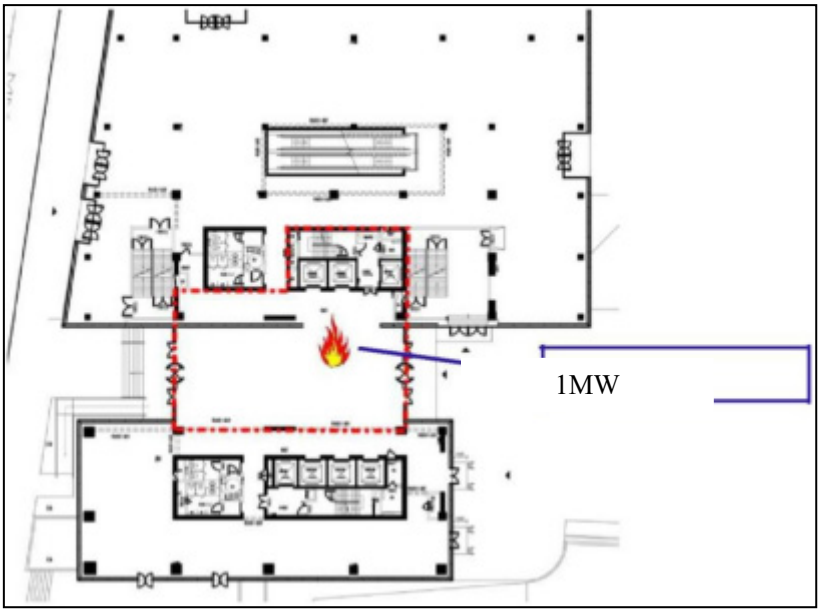


**Figure 8.** Fire scene in the first-floor atrium 1

### 3.2.2 Fire Scenario (NO:02)

Atrium fire Scenario 2:8-floor platform fire is 1MW, with the fire source located in the center of the platform. This fire scenario simulates the spread of smoke in the atrium under the action of smoke exhaust fans on the twelfth and thirteenth floors (smoke exhaust fans on the twentieth floor send alarm signals after detecting smoke according to infrared beam detector) when a fire occurs on the eighth floor platform.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

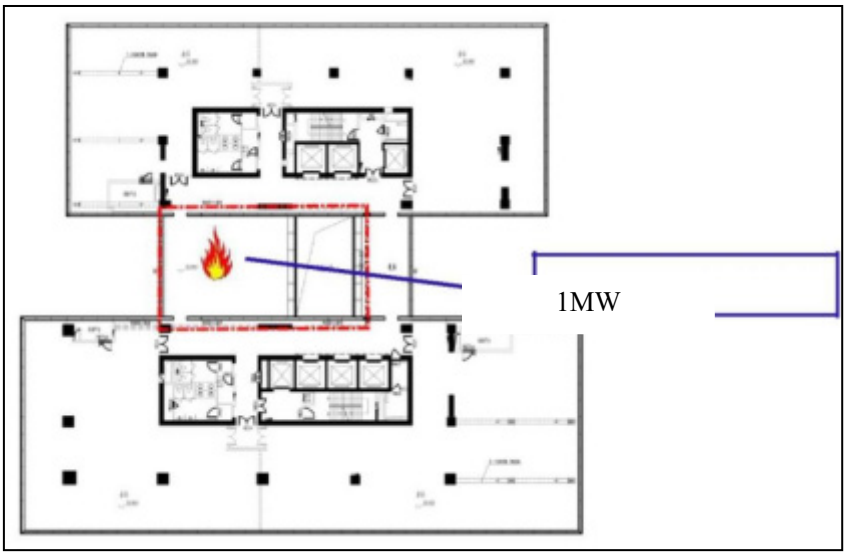


**Figure 9.** Fire scene in the 8th floor atrium 2

### 3.2.3 Fire Scenario (NO:03)

Atrium fire Scenario 3: The fire on the tenth-floor platform is 1MW, and the fire source is located in the center of the platform. This fire scenario simulated the spread of smoke in the atrium under the action of the smoke exhaust fan on the twelfth floor (the smoke exhaust fan on the twentieth floor sends an alarm signal after detecting the smoke according to the infrared beam detector) when a fire broke out on the tenth-floor platform.

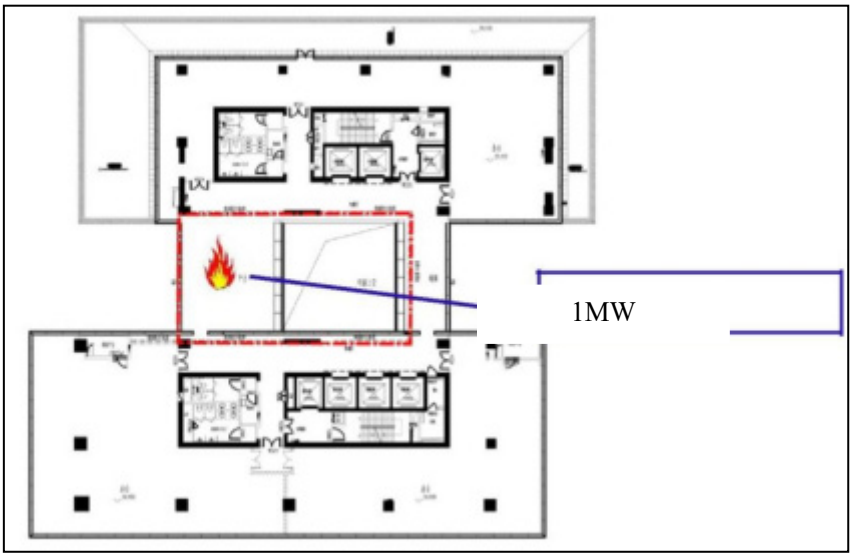


**Figure 10.** Fire scene in the 10th floor atrium 3

## 3.3 Analysis and Conclusion of Simulation Results

According to the above fire scenario simulation results, the safe evacuation time (ASET) that can be provided by the atrium of TC Office building Project in Ningbo under each design fire scenario can be summarized as follows (Table 1):

The results of the 1MW fire simulation on the first floor of the atrium show that when the fire occurs, the smoke rolls up and rises along both sides of the bridge. In each fire scenario, after the exhaust fan of the corresponding floor is started, most of the smoke is quickly discharged from the atrium. After a small amount of smoke rises along the atrium, other smoke exhaust fans start in turn. Due to the large space of the atrium area, there is no obvious stratification in the small-scale smoke. Visibility is maintained throughout the atrium area at all times.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

**Table 1**. The atrium provides a summary of safe evacuation time (ASET)

| Scene | Specific location of fire source | Design fire scale | Floor | ASET |
|---|---|---|---|---|
| 01 | The first floor | 1MW | L1 | >1200 s |
| | | 1MW | L2 | >1200 s |
| | | 1MW | L8 | >1200 s |
| | | 1MW | L10 | >1200 s |
| | | 1MW | L13 | >1200 s |
| 02 | Eight-storey platform | 1MW | L8 | >1200 s |
| | | 1MW | L10 | >1200 s |
| | | 1MW | L13 | >1200 s |
| 03 | Ten-storey platform | 1MW | L10 | >1200 s |
| | | 1MW | L13 | >1200 s |

It can be seen from the FDS simulation results that all fire scenes remain within the human body tolerance limit within 20 minutes of simulation, the visibility of the clear layer 2m above the ground of the corresponding floor and platform exceeds 10m, and the temperature of the clear layer of air does not exceed 60°C except the plume of the fire source. The wind speed of the main inlet of the first floor is about 1.2m/s -- 2.7m/s, and the wind speed of the natural air outlet will not affect personnel evacuation.

Therefore, in the 1MW fire scenario on the first floor of the atrium, the environment can provide no less than 20 minutes of human endurance time, during which people can be safely evacuated.

### 3.4 Optimization Strategy of Atrium Smoke Control after Simulation Analysis

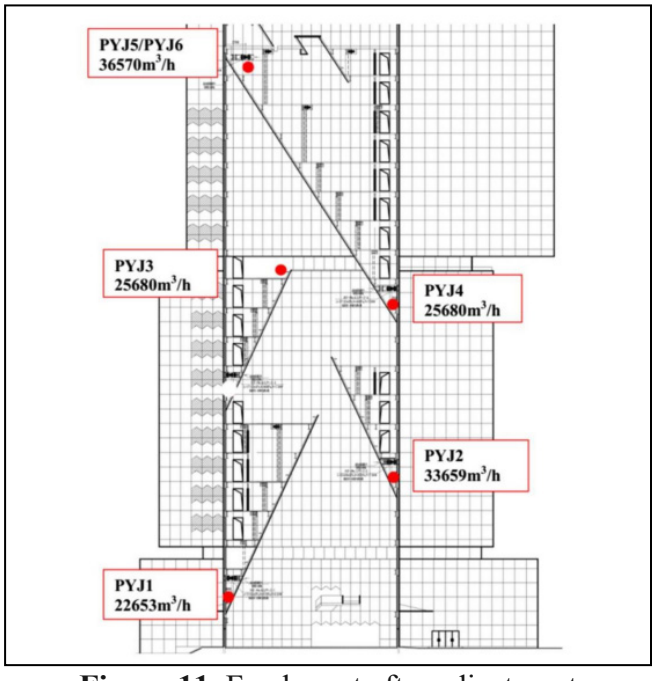


**Figure 11.** Fan layout after adjustment

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

According to the special simulation analysis and comparison, it is found that the existing smoke exhaust scheme is generally feasible in case of fire in the atrium area. However, due to the irregular area of the atrium, the smoke encountered obstacles in the process of rising, and some smoke rapidly fell along the slope of the atrium. The current smoke exhaust system could not fully meet the requirements of smoke exhaust, and the location of local smoke exhaust fans hindered the rise of smoke.

In order to effectively control the smoke exhaust in the atrium, according to the flow of smoke in the simulation trial calculation and combined with the actual situation of the current building, the optimization of the smoke exhaust system in the atrium is as follows:

The smoke exhaust volume of all exhaust fans in the atrium is increased by 50% (that is, the smoke exhaust volume of each area of the atrium reaches 9 air changes per hour);

Adjust the position of the 9-story smoke exhaust fan (PYJ3) from the original 9-story to the 13-story platform floor, as shown in Figure 11.

## 4. Conclusion and Suggestion

High-rise atrium smoke exhaust is different from the simple mode of low and multi-storey atrium buildings (see Figure 12). Due to the increase of height and the change of spatial form, the smoke movement conditions will undergo complex changes. Fire safety analysis should be based on the principles of fire engineering, through a variety of calculation, simulation, qualitative and quantitative analysis to meet the actual fire safety needs, that is, based on the safety requirements of the code and make up for the limitations of the code.

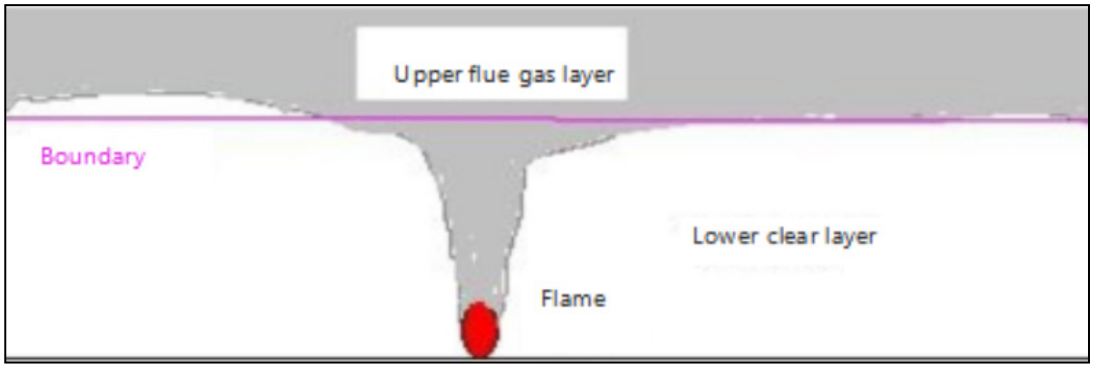


**Figure 12.** Schematic diagram of smoke layer and clear layer in fire site of multi-storey building

Fire smoke contains toxic and harmful gases (such as CO, HCN, CO2, SO2) and unburned solid particle products. Smoke is not only light-reducing, but also irritating to the human eye. The combined effect of the two factors is easy to lead to visual impairment of people in the fire, which has a negative impact on escape and fire rescue. Moreover, if the smoke layer in the fire site is low, the oxygen concentration in the height range of the personnel will inevitably decrease, which may lead to asphyxia injury. Therefore, it is of great significance to keep the smoke at a certain height (i.e., clear height of the smoke layer) and effectively eliminate the smoke in the fire [6]. At the same time, in addition to considering the smoke part of the factors, other fire facilities and measures should also be implemented synchronously:

1) All decoration materials should choose non-combustible or non-combustible materials;

2) The atrium is only used as a traffic area, not as commercial, catering (including coffee), exhibition (including holiday publicity materials or decorated Christmas trees) and other functional places;

3), before the construction of the development of a detailed construction scheme of fire shutter, to ensure that fire shutter has sufficient installation space; Later use, is not allowed to stack goods or garbage below the fire shutter, and send special supervision and management, in order to prevent the fall of fire shutter;

ISSN: 2414-1895 DOI: 10.6919/ICJE.202305_9(5).0031

4) The evacuation exit plays a vital role in the evacuation process, which should be strengthened in the daily fire management to ensure smooth, so as to ensure the safety of the building personnel evacuation in the event of a fire.

5) In the later stage, make maintenance management plan and regularly maintain firefighting equipment to ensure that all firefighting systems are in working condition and can be effectively started in case of fire. In case of failure of firefighting system, the personnel on duty should be notified and relevant preventive measures should be taken before repair;

6) The maintenance and management personnel of firefighting equipment shall receive professional training in firefighting and be familiar with the principle and operation of each firefighting system;

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