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Research on Design and Safety Management of Modern Building Fire Protection Systems

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Abstract: This paper explores the key issues in the design and safety management of modern building fire protection systems. With the acceleration of urbanization and the increase in high-rise buildings, building fire safety is facing new challenges. The research analyzes the design principles, key components of fire protection systems, and safety management measures, and puts forward optimization suggestions. The results show that scientific and reasonable design of fire protection systems and strict safety management are crucial for preventing fires and reducing losses. This study provides a theoretical basis and practical guidance for the improvement of building fire protection systems.

Keywords: Building fire protection; System design; Safety management; Fire prevention; Emergency evacuation

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1. Introduction

With the acceleration of urbanization and the continuous increase of building height, the issue of building fire safety has become increasingly prominent. In recent years, several major building fire accidents at home and abroad have caused serious casualties and property losses, highlighting the importance of the design and safety management of building fire protection systems. This study aims to explore the scientific design methods and effective safety management strategies of modern building fire protection systems, so as to provide theoretical support and practical guidance for improving the level of building fire safety.

2. Principles for the design of building fire protection systems

The design of building fire protection systems shall follow the basic principle of "prevention first, combining prevention and fire fighting". First, the design must comply with relevant national laws, regulations, and standards, such as the Code for Fire Protection Design of Buildings and the Code for Design of Automatic Sprinkler Systems. These standards provide basic technical requirements and parameter criteria for the design of fire protection systems.

Second, the design of fire protection systems shall fully consider factors such as the building's usage nature, height, and area. Different types of buildings have varying requirements for fire protection systems. For example, high-rise buildings require stricter fire compartmentation and more comprehensive evacuation systems, while crowded places need more sensitive alarm systems and smoother evacuation routes. Once a fire breaks out in a high-rise building, a

large amount of thick smoke will be generated on site, with an abnormally large range of thermal radiation, and the fire will spread rapidly. In such an accident environment, rescue work is more difficult, requiring more water resources to extinguish the open fire. Additionally, due to the height of high-rise buildings, water supply faces a series of technical challenges, making it impossible to extinguish the fire and carry out rescue in the shortest time. As high-rise buildings, their height and volume are different from those of multi-story buildings, and their water pressure requirements and water supply safety requirements are essentially different from those of domestic water supply systems. The fire water supply system for high-rise buildings and general domestic water supply systems should adopt a separate supply design, which is also an issue to be considered in the design process of engineering projects. In terms of water demand, the amount of water required for fire fighting is very large. Given this special water supply requirement, the design of fire pump rooms and fire water tanks in high-rise buildings is particularly important.

Finally, the design of fire protection systems should focus on balancing reliability and economy. The system shall ensure reliable operation in the event of a fire, while considering construction and maintenance costs to avoid resource waste caused by over-design. Mature and reliable technologies and equipment should be adopted to ensure the long-term stable operation of the system. Designers should collaborate with construction teams. The automatic fire alarm and fire linkage system is the first line of defense to detect fire signs in a timely manner and reduce fire losses. If the selection and placement of fire detectors are inappropriate, it may bring hidden dangers to safety management. For example, using detectors unsuitable for gas environments, or unreasonable placement of detectors that fail to cover all key areas, may lead to failure in timely detection of initial fires, delaying alarm and fire fighting. Especially in gas leakage areas, incorrect detector types may increase risks due to false alarms or missed alarms. If the control program design of fire linkage devices is unreasonable, such as improper setting of the startup sequence or conditions for equipment like automatic sprinkler systems, smoke exhaust fans, and fire broadcasting systems, in the event of a fire, chaotic or delayed linkage control may lead to ineffective use of fire resources, and may even hinder personnel evacuation or fire fighting operations due to incorrect equipment startup sequences. Furthermore, there may be a lack of regular maintenance and functional testing for the automatic fire alarm and fire linkage system, leading to system aging, sensor failure, or failure of linkage functions.

3. Key components of building fire protection systems

Modern building fire protection systems mainly consist of the following key components: automatic fire alarm systems, automatic sprinkler systems, smoke control and extraction systems, emergency lighting and evacuation indication systems, and fire power supply systems.

The automatic fire alarm system is the “nerve center” of the fire protection system, composed of detectors, manual alarm buttons, alarm controllers, etc. It can detect fires in a timely manner and issue alarms, gaining valuable time for personnel evacuation and fire fighting. The automatic sprinkler system is the most common automatic fire-extinguishing facility. It is automatically activated by the sprinkler heads that sense temperature, which can effectively control incipient fires. Reasonable and effective control of temperature is important because temperature changes are a significant cause of cracks in concrete. However, temperature is a factor with large variations, making it difficult to effectively control it at all times. Therefore, when controlling temperature, it is necessary to strictly follow the standards. Before concrete pouring, relevant data such as volume should be used to calculate the temperature that can be reached during pouring, so as to realize effective control of concrete temperature changes.

The smoke control and extraction system ensures the relative safety of evacuation routes through mechanical pressurized air supply and smoke extraction. In the design of smoke control and extraction systems, the main purpose of dividing zones is to effectively limit the diffusion range of high-temperature smoke in the fire site within a certain period, prevent its unordered spread, and thus ensure the safe evacuation of personnel, curb the expansion of the fire, and reduce the damage caused by the fire. When carrying out zone design, it is essential to ensure that the zone boundaries do not exceed the fire compartment. For special functional areas such as smoke-proof staircases, fire elevators, and refuge floors,

separate smoke control and extraction zones must be set up to fully ensure the smooth flow of personnel evacuation paths and fire-fighting operations. If a specific area is not equipped with smoke extraction facilities, there is no need to divide smoke control and extraction zones in that area. The emergency lighting and evacuation indication system provides lighting and direction guidance in case of power failure, ensuring the safe evacuation of personnel. The fire power supply system provides backup power for key fire-fighting equipment, ensuring that fire protection facilities can still work normally in case of power failure. The automatic sprinkler system is one of the main fire-extinguishing means for high-rise buildings. In the design of automatic sprinkler systems, the selection of sprinkler heads should be reasonably arranged according to factors such as the fire risk, layout, and personnel density of high-rise buildings. The type of sprinkler heads, spray distance, spray pattern, etc., should match the characteristics of high-rise buildings. Based on factors such as the area, floors, personnel density, and fire compartments of high-rise buildings, the water flow and water pressure required for the automatic sprinkler system are calculated. This will ensure that the system can provide sufficient fire-extinguishing water during a fire and effectively control the fire. The automatic sprinkler system requires reliable control and monitoring mechanisms, including fire alarm systems, water pump control systems, and opening/closing control of sprinkler valves. These control and monitoring technologies can ensure the timely response and effective operation of the system.

4. Building fire safety management measures

A sound fire protection system can only exert its maximum effectiveness when supported by strict safety management. First, a sound fire safety responsibility system should be established. It is necessary to clarify the fire-fighting responsibilities of managers at all levels and employees, forming a fire safety management system with full participation.

Second, regular inspection, maintenance, and upkeep of fire-fighting facilities should be conducted. This includes testing alarm systems, checking the pressure of fire extinguishers, cleaning sprinkler heads, etc., to ensure all equipment is in good condition. Meanwhile, a comprehensive fire protection file should be established to record the operation status and maintenance of equipment. As the two most important components of a building's fire protection system, research on the reliability of automatic alarm systems and fire-extinguishing systems is currently a hot topic. The reliability of an automatic alarm system refers to the comprehensive performance of the monitoring system in terms of the timeliness of response to fire information (response time) and accuracy (false alarm rate, missed alarm rate) [1]. Missed alarms and false alarms are the main problems faced by alarm systems, and a relatively complete discussion has been given in references [2]. How to improve the accuracy of fire judgment and reduce the probability of false alarms and missed alarms is an important research direction for current automatic alarm systems. Most fire-extinguishing media used in fire-extinguishing systems are water, so the reliability of the system largely depends on the fire water system. In recent years, the number of high-rise buildings in China has been increasing, which has put forward higher requirements for the supply of water systems. Research on the reliability of fire-extinguishing systems has focused more on fire water systems.

Third, fire safety training and drills should be strengthened. Regular fire knowledge training and emergency evacuation drills for employees should be organized to improve their awareness of fire prevention and their ability to save themselves and others. In particular, special training should be provided for newly recruited employees and personnel in key positions. In the fire prevention design of public building decoration, complete fire-fighting facilities, including fire extinguishers and fire hydrants, should be equipped in accordance with relevant regulations. After installation, regular inspections should be carried out to ensure that the fire-fighting facilities are effective and can be used normally in case of fire. In addition, whether it is a shopping mall, school, hospital, or office building, users should be informed that fire-fighting facilities are prohibited from being blocked during exterior wall decoration. Especially for restaurants in shopping malls, in order to receive more customers, they often set up tables and chairs on the outer eaves and decorate with flowers and plants. In such cases, if fire awareness is weak or for the sake of beauty, it is extremely easy to block fire extinguishers and fire hydrants, which may cause these fire-fighting facilities to fail to function properly in case of fire [3]. Therefore, in addition to regular inspections, publicity and education work should be implemented through distributing publicity

manuals, conducting lectures, organizing training, and one-on-one notifications to improve people's fire awareness and fire-fighting behavior. In the decoration design of public buildings, the planning of escape routes and evacuation indicators is crucial. Reasonable escape routes should be arranged according to the nature and functional use of the building to ensure that the width and height of the routes can meet the evacuation needs of a large number of people at the same time. In the decoration design, priority should be given to ensuring that the main escape routes are unobstructed. Obstacles such as furniture and decorations should not be placed in the routes to ensure that people can evacuate quickly and orderly in case of fire. In addition, the setting of evacuation indicator signs is also extremely important. Obvious evacuation signs should be set in accordance with relevant national standards to ensure that people can quickly identify the evacuation direction during a fire. At the same time, regular fire drills should be organized to improve the safety awareness of staff and users, make them familiar with evacuation routes, and enable them to respond calmly and evacuate calmly in case of fire or other emergencies. After the drill, summaries and feedback can be carried out to gradually improve the setting of escape routes and evacuation indicators, ensuring the safe operation of public buildings.

Finally, an emergency response plan and a rapid response mechanism should be established. Detailed disposal procedures should be formulated for different types of fires, and the action responsibilities of personnel in various positions should be clarified to ensure that fires can be dealt with quickly and effectively when they occur.

In high-rise buildings, a series of effective measures must be taken to ensure the safe evacuation of people. First, building designers should give priority to evacuation routes. Stairs, walkways, and passages should be reasonably arranged, spacious and bright, and meet building safety standards. Second, a sufficient number of fire-fighting passages should be set up in high-rise buildings, and they must always be kept unobstructed. Regular fire inspections and drills should be conducted to check and clean equipment such as smoke detectors and sprinkler heads in evacuation routes. In addition, evacuation routes in high-rise buildings should be marked with clear evacuation signs and indicators so that people can quickly find and follow the instructions to escape in case of fire. At the same time, emergency shelters and safety exits should be set up in the building for people to take temporary shelter and evacuate in case of fire. Fire evacuation in high-rise buildings is an important and complex task[4]. To ensure people's safety, building designers should give priority to the setting of evacuation routes. Evacuation routes in the building should be kept unobstructed and equipped with clear evacuation signs and indicators[5]. Residents and office workers should also strengthen their awareness of fire evacuation, participate in regular drills, and master correct escape methods. Only through joint efforts can we ensure the timely evacuation and personal safety in case of fire in high-rise buildings.

5. Conclusion

The design and safety management of building fire protection systems are crucial aspects in ensuring building safety. Scientific fire protection system design should comply with relevant specifications, take into account building characteristics, and balance reliability and economy. A comprehensive fire protection system includes multiple subsystems such as alarm, fire suppression, smoke prevention and exhaust, and evacuation, which need to work in coordination. Strict safety management measures, such as the establishment of responsibility systems, equipment maintenance, personnel training, and emergency preparedness, are key to ensuring the effective operation of fire protection systems[6].

In the future, building fire protection will develop towards intelligence and integration, utilizing technologies such as the Internet of Things and big data to improve fire early warning and disposal capabilities. At the same time, green and environmentally friendly fire-extinguishing technologies and materials will also be more widely applied. Building fire protection work requires the joint efforts of designers, constructors, and managers to create a safer living and working environment for people.

Disclosure statement

The author declares no conflict of interest.

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