

OPTIMIZATION OF FIRE PROTECTION SYSTEMS IN BUILDINGS AND STRUCTURES

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Abstract. *The rapid growth of high-rise buildings with complex designs in Uzbekistan has intensified fire safety challenges, including vertical fire spread and evacuation complexities. This article explores the optimization of fire protection systems through integrating passive measures (structural resistance, compartmentation) and active systems (sprinklers, smoke management, standpipes, communication networks). It advocates adopting modern technologies such as AI detection, IoT sensors, and drone operations, aligned with international standards (NFPA, IBC). Recommendations emphasize maintenance, emergency planning, and training to enhance resilience and ensure life safety in Uzbekistan's urban development.*

Keywords. *Fire protection systems, high-rise buildings, optimization, passive fire protection, active fire suppression, smoke management, evacuation strategies, structural fire resistance, modern technologies, emergency planning, Uzbekistan urban development, NFPA standards, IBC codes.*

Introduction. As is known, today, similar to developed countries, the number of high-rise skyscrapers and structures with complex designs and structural features is rapidly increasing in the territory of the Republic of Uzbekistan. In 2024, over 40 million square meters of buildings were constructed across the country, including 2,044 multi-story residential buildings with more than 100,000 apartments.

This trend has continued into 2025, with construction output reaching approximately 137.6 trillion soums in the first half of the year alone—a 10.7% increase compared to the same period in 2024—driven by investments in residential, commercial, and infrastructure projects.

The tallest structure, Nest One in Tashkent at 266.5 meters, exemplifies this development, incorporating advanced international fire safety standards such as firefighting elevators, emergency lighting systems, backup generators, and comprehensive monitoring.

However, this rapid urbanization heightens fire risks in high-rise buildings, where vertical fire spread, smoke propagation, and evacuation complexities pose significant challenges. National



statistics indicate thousands of fire incidents annually, with a notable portion linked to residential and multi-story structures, underscoring the urgent need for optimized fire protection systems.

To address these risks effectively, modern high-rise developments in Uzbekistan must integrate both active and passive fire safety measures, aligned with evolving national regulations and international best practices (e.g., NFPA and IBC standards). Recent policy advancements,



including bans on combustible façade materials and enhanced monitoring requirements introduced in 2024–2025, further emphasize the prioritization of resilient designs.

Optimizing fire protection systems involves adopting innovative technologies such as AI-driven early detection, IoT sensors, automatic sprinklers, smoke management systems, and drone-assisted operations, while ensuring structural fire resistance and reliable evacuation pathways.

This approach not only minimizes damage and protects lives but also supports sustainable urban growth amid Uzbekistan's ongoing construction boom.

This process necessitates the optimization of fire protection systems in buildings and structures to meet modern requirements, as well as the introduction of new methods and technologies. In particular, fire suppression in high-rise buildings involves the complexity of rescue operations, requiring personnel of rapid-response fire units to have comprehensive knowledge of fire development processes and characteristics, along with high professional skills, physical and psychological preparedness.

Furthermore, the use of modern technologies in skyscrapers, accounting for fire risks and operational-tactical features, enables minimizing fire damage and taking prompt measures to protect human life and health.

Currently, the increase in building height norms has led to the active construction of buildings over 80 meters in Uzbekistan's major cities (the highest indicator is the Nest One skyscraper with a height of 266.5 meters, equipped with international-standard fire safety features such as firefighting elevators, emergency lighting systems, and backup generators).



High architectural and unique design requirements are leading to the construction of non-standard structures in urban planning. This places new demands on fire protection systems: the adoption of modern fire suppression systems, collective rescue tools, new equipment, and tactical optimization.

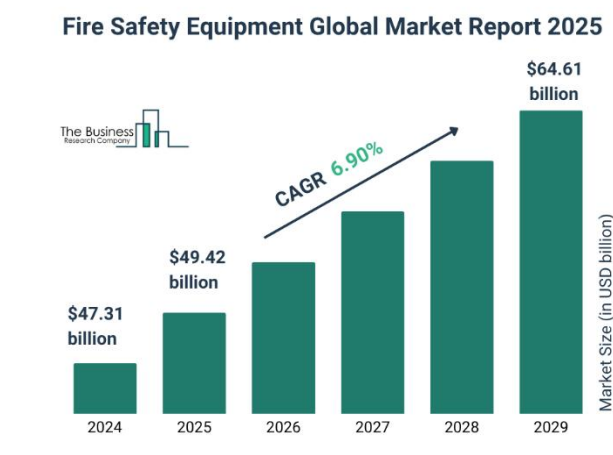


The relevance of the topic is further highlighted by the fact that a significant portion of fire and emergency incidents observed annually in the republic (for example, in 2023–2024, hundreds of thousands of responses, with thousands of lives saved) are directly related to high-rise residential



buildings and structures. The provided image is a bar chart infographic titled "Fire Safety Equipment Global Market Report 2025", published by The Business Research Company. It visually represents the projected growth of the global fire safety equipment market from 2024 to 2029, expressed in USD billion. Key Data Points Depicted:

2024: \$47.31 billion
 2025: \$49.42 billion
 2026–2028: Progressive increases (approximate values based on the upward trend, not explicitly labeled)
 2029: \$64.61 billion



Growth Indicator: A prominent arrow highlights a Compound Annual Growth Rate (CAGR) of 6.9% over the forecast period, driving the market from approximately \$47–49 billion in the mid-2020s to \$64.61 billion by 2029.

Visual Elements:

Teal-colored ascending bars illustrate year-on-year market expansion.

The chart emphasizes steady growth driven by factors such as increasing construction activity, urbanization, regulatory compliance, and demand for advanced fire protection solutions.

This infographic is derived from The Business Research Company's comprehensive market research report, which analyzes historical trends, current market dynamics, and future forecasts for the fire safety equipment industry. The report attributes forecast growth to rising demand for eco-friendly solutions, climate-related fire risks, data center expansion, building retrofitting, and infrastructure development.

Note: Some variations in projected figures appear across related reports (e.g., alternative estimates suggest \$67.15 billion by 2029 at a 7.6% CAGR), reflecting differences in scope, methodology, or updates. The depicted data aligns precisely with one of the primary versions published by The Business Research Company in 2025.

Literature review on the topic. Fires in multi-storey buildings can lead to catastrophic consequences due to a number of unfavorable factors, including the use of combustible materials in building structures and interior finishes; malfunctioning or improper operation of automatic fire alarm and fire-extinguishing systems; and the presence of openings between floors, ceilings, stairwells, and shafts, which contribute to the rapid vertical spread of fire and dense smoke. These conditions significantly reduce the effectiveness of fire suppression and rescue operations. The general principles for organizing fire-fighting and rescue operations are defined in a number of regulatory documents of the Ministry of Emergency Situations of the Republic. However, these materials do not allow for reliable prediction of the possible consequences of fires in modern multi-storey buildings, nor do they provide sufficiently accurate calculation methods. While the calculation of the required fire protection forces and resources, as well as the consumption of water and other fire-extinguishing agents necessary for effective fire-fighting and rescue operations, remains a critical issue, another equally important aspect is that modern information technologies have not yet been effectively implemented in the activities of fire protection agencies. As a result, the level of automation in managing operational fire-fighting and rescue units remains very low.



Methods. This study employs a mixed-methods approach to evaluate and optimize fire protection systems:

Statistical Analysis: Review of national fire incident data from the Ministry of Emergency Situations (e.g., over 10,000 fires in 2023, with significant portions in residential high-rises) and global benchmarks.

Comparative Analysis: Alignment with international standards (NFPA, ISO) and case studies of high-rise fires.

Simulation Modeling: Use of software tools (e.g., Fire Dynamics Simulator - FDS, Pathfinder) to model fire spread, smoke propagation, and evacuation in structures similar to Nest One (266.5 m, equipped with firefighting elevators and backup systems).

Technological Assessment: Evaluation of emerging tools including AI-driven monitoring, drones for reconnaissance, and automated suppression systems.

Expert Surveys: Input from rapid-response fire units on tactical challenges in high-rise rescue operations.

Modern high-rise buildings' fire safety systems must meet the following requirements:

Modern high-rise buildings must incorporate both active and passive fire protection features to control fire growth and minimize the impact of fire on the structure and its occupants.

Active systems include automatic sprinkler protection to contain and suppress fires in limited areas, as well as smoke management systems to control smoke movement and facilitate safe occupant evacuation.

Passive elements encompass fire-resistant construction and fire barriers to prevent vertical fire spread.

All active and passive systems must be maintained throughout the building's lifespan to ensure proper operation when needed.

Means of egress that facilitate occupant evacuation during a fire incident. Occupants must remain protected from fire effects within the building while evacuating from the fire area. Fire-rated enclosed and positively pressurized stairwells protect evacuees from fire and smoke exposure during descent.

Fire detection, alarm, and communication systems that alert building staff to the occurrence of a fire and provide instructions to occupants for evacuation.

Firefighting support systems that primarily enable operations conducted from within the building, often in locations remote from ground-based firefighting apparatus and support. These systems include vehicle access, firefighters' elevators, fire command centers, standpipe (wet riser) systems, and firefighter communication networks.

In addition, building response plans and procedures should be closely coordinated with first responders.

Implementing a successful fire safety approach in the design of new high-rise projects or the renovation of existing structures is critically important under current technical standards. The technical design of high-rise buildings should always begin with establishing the regulatory framework for the project. This is achieved by identifying the applicable local codes and standards—even in locations with numerous tall buildings.

Some high-rise buildings are significantly taller and more complex than anticipated by building codes. For many projects, prescriptive building codes may not fully address fire safety concerns, necessitating the establishment of an enhanced performance-based requirement level to “improve” the fire and life safety aspects of the design.

Operations conducted during a fire incident. High-rise fire safety strategies rely heavily on active fire systems and complex evacuation sequences. Consequently, the operational aspects of



high-rise buildings are of critical importance. To ensure their reliability in emergencies, active fire systems must be continuously monitored, maintained, and tested.

Another key operational aspect is emergency planning and training. This begins with an Emergency Management Plan that outlines all foreseeable emergency scenarios and the responses of building personnel to those incidents. The Emergency Management Plan should identify all threats—whether natural disasters, terrorism, security issues, or systemic emergencies—and include pre-planned response procedures for each event. These procedures must incorporate staff training and drills.

Future Directions in High-Rise Fire Safety

In the future, the design and operation of high-rise fire safety will involve increasingly sophisticated active fire systems for fire control, smoke management, evacuation, and firefighting. Enhancing the fire resistance and structural integrity of buildings to ensure they remain standing, along with guaranteeing the reliability of critical building features, will become more important than all other requirements.

Conclusion. The rapid expansion of high-rise construction in Uzbekistan, mirroring trends in developed countries, presents significant advancements in urban development while introducing heightened fire safety challenges. The increasing prevalence of skyscrapers with complex designs and unique structural features amplifies risks associated with vertical fire spread, smoke propagation, and complicated evacuation procedures.

This study emphasizes that effective optimization of fire protection systems necessitates a comprehensive integration of passive measures—such as structural fire resistance, compartmentation, and non-combustible materials—with active systems, including automatic sprinklers, smoke management, standpipes, voice communication networks, and stairwell re-entry provisions. The adoption of emerging technologies, including AI-driven early detection, IoT sensors, drone-assisted reconnaissance, and advanced suppression methods, further strengthens response capabilities and overall system performance.

In summary, sustained focus on system maintenance, emergency planning, personnel training, and performance-based design is essential to mitigate risks, safeguard lives, and promote safe, sustainable high-rise development. Proactive collaboration between designers, regulators, and first responders will be critical to addressing the evolving demands of modern urban environments in Uzbekistan.

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