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ASSESSING FIRE RISKS AND EMERGENCY PREPAREDNESS IN COMMERCIAL BUILDINGS: A REVIEW OF PROTECTION, EVACUATION, AND HUMAN FACTORS

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ABSTRACT

The commercial buildings host a larger number of people, engage in many activities, use complicated building system and have combustible materials, which makes the need for fire safety crucial. This review looks at fire risk assessment and preparedness for emergencies in commercial buildings, with regard to the significant risks associated with fire, fire risk assessment methods, fire protection, evacuation planning, human behaviour, and emergency management. An integrative literature review approach was adopted involving use of research articles, fire-safety literature, risk management literature and Indian building safety rules. The review shows that fire risk arises from electricity risks, combustible materials, building design, smoke movement, human element, maintenance, and emergency response. The effective fire safety involves the combination of active and passive fire protection, maintenance of inspections and maintenance, training of employees, fire drills, communication during emergencies, and proper evacuation plan. The review shows some problems associated with regulation compliance, lack of training, human behaviour, building complexity, and integration of risk assessment methods. Generally, the need for an integrated and continuous fire risk assessment and emergency preparedness in commercial buildings is evident.

Keywords: *Fire Risk Assessment; Emergency Preparedness; Commercial Buildings; Fire Safety; Evacuation; Human Behaviour.*

1. INTRODUCTION

The complexity of commercial buildings is increasing because of many reasons like the pace of urbanization, high density of population, vertical growth, multipurpose buildings, extensive electricity and mechanical services, and the use of modern materials and technologies. Many occupants can be present in offices, shopping centers, hotels, restaurants, banks, information technology centres, entertainment centers, business centers, and multi-purpose commercial buildings at the same time [1]. The presence of high occupant density, diversified functions, combustible materials, electricity services, cooking services, storage spaces, and other building services has made fires one of the most possible risks in such buildings. The National Building Code of India (NBC 2016) includes fire and life safety measures that are integral parts of building construction and management.

Figure 1: Fire Risk Assessment [2]

The risk of fire in commercial buildings depends on multiple interacting factors and not only the existence of fire starters. They include the probability of fire ignition, building features, amount and types of combustible substances, fire protection systems, behaviour of the population, capacity for emergency reactions, and consequences of fires.

Fire risk assessment represents an approach that helps identify risks, evaluate their probability and consequences, and whether there are sufficient preventative and protection measures in place.

Emergency preparedness is another equally significant element of fire safety in commercial buildings because the efficiency of technical fire prevention systems will be determined by people's proper reaction during an emergency situation. Prompt identification of danger, appropriate alarm signaling, accessible exit paths, emergency lighting, trained personnel, evacuation planning, and coordination with emergency responders can make a difference in ensuring the desired life-safety result. Emergency preparedness thus should not be limited only to fire drills but should also involve a clear definition of duties, communication procedures, help to vulnerable occupants, inspection and maintenance, staff training, and drill analysis. Although there are fire-safety regulations and means of assessing fire safety in commercial buildings, there still exist differences between fire safety regulations and their practical implementation [3].

1.1 Objectives of the Review

Objectives of the review include the following:

- To understand the major fire risks, risk factors, and methods of fire risk assessment in commercial buildings.
- To study the role of fire protection, emergency preparedness, evacuation plans, and training and drills in improving the safety of occupants in commercial buildings.
- To understand the major issues, human factors, and emerging technologies affecting fire risk management and emergency preparedness in commercial buildings.

2. REVIEW METHODOLOGY

An integrative literature review method has been used to review literature in relation to fire risk assessment and emergency preparedness in commercial premises. The reason for using this method is that fire safety encompasses several fields like fire engineering, architecture, risk management, human behaviour, emergency management, and organizational safety. The review has taken place using a qualitative and descriptive method as illustrated by the attached example [4].

The literature covered research papers, review articles, research reports, literature on fire safety, international guidelines on risk management, and Indian guidelines for safety in buildings. There was a special focus on research papers related to commercial buildings, high rise buildings, fire risk assessment, fire safety systems, evacuation, and fire safety management.

The literature sources were arranged according to themes such as fire hazard and risk factors, fire risk assessment, fire prevention and protection, emergency preparedness and evacuation, human behaviour, fire safety management, and new technological advancements. The results were synthesized qualitatively to find major trends, challenges, and gaps in research [5].

3. FIRE RISK IN COMMERCIAL BUILDINGS

Some of the important aspects of fire safety in commercial buildings include the identification and management of fire hazards caused by various activities, occupancies, building systems, and human factors. Commercial buildings might comprise offices, retail premises, restaurants, stores, and other occupancies within the same building, with each occupancy posing its own risk of fire hazards [6]. There might be electrical systems, combustible substances, cooking systems, mechanical systems, HVAC systems, and human activity that cause the initiation and growth of fire. High-rise commercial buildings face additional problems in relation to vertical evacuation, smoke flow, firefighting operations, and communications. The National Building Code of India provides fire and life safety provisions related to fire prevention, protection, escape routes, occupant load, compartmentation, smoke control, fire detection, alarms, and firefighting installations.

3.1. Major Sources of Fire Hazards

There are different ignition sources that can cause fire hazards in commercial structures. Electrical ignition sources like overloaded circuits, malfunctioning wiring, damaged equipment, poor connections, and lack of maintenance may serve as potential ignition sources. Combustibles such as paper, plastic, fabrics, packaging, furniture, chemicals, and

merchandise may be considered as factors contributing to fast fire development and generation of smoke. Ignition sources used for cooking and heating, like open flame, heat surfaces, cooking oil, gas equipment, and accumulated grease, can be found in restaurants, cafeterias, and food courts [7].

Human factors are yet another source of fire hazards. Smoking, improper use of electric devices, improper modifications of building features, poor maintenance, hazardous storage, and failure to comply with fire-safety practices may raise the chances of fire occurrence. Deficiencies of a building may include inadequate compartmentation, blocked exits, inadequate escape facilities, improper signage, inadequate fire resistance, and poor smoke management system, among others. Hence, fire safety in commercial buildings must take into account both physical and human elements [8].

3.2. Major Fire-Risk Factors

Several factors that have an influence on the fire risk in commercial buildings are interrelated to one another. These include types of hazards, possibility of ignition, presence of flammable material, building layout, movement of smoke, human behavior, fire protection system efficacy, and emergency management [9]. These factors, their possible impacts, and control strategies have been presented in Table 1.

Table 1: Major Fire-Risk Factors in Commercial Buildings [10]

Risk Category	Typical Hazards	Key Control Measures
Electrical	Faulty wiring, overloading	Inspection and maintenance
Combustible Materials	Paper, plastics, textiles	Safe storage and housekeeping
Cooking	Gas, flames, grease	Cleaning and suppression systems
Building Design	Poor exits, inadequate compartmentation	Safe design and egress
Smoke Movement	Smoke through shafts/HVAC	Smoke control systems
Human Factors	Unsafe practices, delayed response	Training and awareness
Fire Protection	Poor maintenance or system failure	Regular testing and maintenance
Emergency Management	Poor planning and communication	Emergency plans and drills

Table 1 illustrates that fire risks associated with commercial buildings are multilateral and cannot be mitigated through a single action [11]. Hazard identification must then be followed by necessary precautions, proper fire protection systems, maintenance, human training, and emergency preparation. An approach that incorporates the design of the building, fire protection, human factors, and emergency management will be crucial to reduce the risks associated with fires.

4. FIRE RISK ASSESSMENT IN COMMERCIAL BUILDINGS

Fire risk assessment is an essential element of fire safety management in business buildings. It comprises such steps as identification of fire risks, assessment of the probability of the risk and its consequences, identification of current precaution and protection measures, and definition of additional necessary actions that could help mitigate fire risk [12]. Fire risk assessment must be considered an ongoing procedure, not an isolated one-time inspection, as conditions in the building and activities carried out there may vary from time to time. ISO 31000 presents a set of principles to risk identification, analysis, evaluation, treatment, monitoring, and communication, which may be applied to fire-risk management with regard to specific risks in particular buildings.

4.1. Components of Fire Risk Assessment

Fire hazard assessment is an interrelated process consisting of multiple steps such as building/occupancy description, identification of ignition sources, combustibles, fire growth/spread analysis, passive/active fire protection systems assessment, assessment of means of escape and evacuation, occupant characteristics assessment, emergency response assessment, and maintenance/managing system inspection [13]. Fire hazard assessment shall also cover risk assessment, prioritization of risk reduction actions, implementation of risk control measures, and re-assessment on a regular basis. These activities allow evaluating both the probability of a fire occurrence and the consequences of that

event. Even if the probability of a hazard occurrence is quite small, such hazard shall be considered risky if there is a possibility for that hazard to result in serious injuries, deaths, or significant damages.

Figure 2: Components of Fire Risk Assessment [14]

4.2. Fire Risk Assessment Techniques

Various methods of assessing fire risk can be used depending on the nature and complexity of the commercial building and the reason for conducting the assessment [15]. Methods include checklists, risk matrices, Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Hazard and Operability Analysis (HAZOP), Analytic Hierarchy Process (AHP), fuzzy AHP, quantitative fire risk assessment, and evacuation simulation. The different methods offer different degrees of detail and can help in identifying hazards, risk prioritization, failure analysis, consequence analysis, and evacuation effectiveness evaluation [16].

The study of big commercial buildings and high-rises has shown how multi-criteria and AHP-based approaches with fuzzy logic were used in order to involve expert evaluation and take into account the uncertainty caused by different fire hazards. Even more sophisticated methods included intuitionistic fuzzy models and social network analysis techniques for assessing relationships between fire safety factors [17]. The major approaches to fire risk assessment and their features are shown in Table 2.

Table 2: Major Fire Risk Assessment Approaches [18]

Assessment Approach	Main Purpose	Key Advantage
Checklist	Hazard identification	Simple and practical
Risk Matrix	Risk ranking	Easy prioritization
FMEA	Failure analysis	Identifies system failures
FTA	Cause analysis	Identifies risk pathways
ETA	Consequence analysis	Evaluates possible outcomes
AHP/FAHP	Risk prioritization	Uses expert judgement
Quantitative Assessment	Risk calculation	Detailed analysis
Evacuation Simulation	Evacuation assessment	Evaluates egress performance

From what is presented in Table 2, it is clear that fire risk assessment techniques range from qualitative checklist methods to more quantitative and simulation methods. Checklists and risk matrices serve as valuable tools for inspection and initial risk evaluation, while FMEA, FTA, and ETA can give more elaborate failure and consequence evaluation for the system. AHP and FAHP methods are valuable in cases when many risk factors should be taken into account. Quantitative risk assessment and evacuation simulation techniques can give more detailed data for complex buildings, although they are more demanding in terms of knowledge and data availability.

5. FIRE PREVENTION AND FIRE PROTECTION MEASURES

Fire prevention and fire protection form an essential part of the overall safety aspects of commercial buildings. The first and foremost goal is to make sure that fires are not initiated and that, in case of a fire outbreak, there will be early detection, controlling, protection, and firefighting [20]. Fire prevention, life safety, and fire protection are covered by the NBC 2016 in provisions for fire-resistant structures, compartmentalization, fire escapes, emergency lighting, signage, smoke control, fire detection and alarm system, extinguishers, sprinklers, hydrants, water storage, pumps, etc.

- **Passive Fire Protection:** Passive fire protection comprises features which provide continuous protection of a building without the need for any activation of these features. These features include fire-resistant walls and floor assemblies, fire doors, compartmentation, protected stairways, fire stopping, smoke barriers, protected shafts, structural fire resistance, and hazardous area separation. The compartmentation feature is especially important since it limits the mobility of the fire and smoke and gives additional time for the safe evacuation of people.
- **Active Fire Protection:** Active fire protection is represented by the systems which need detection, activation or human intervention to work. The main fire protection systems are automatic fire detection and alarm systems, sprinklers, hydrants, hose reels, fire extinguishers, wet risers, fire pumps, water storage systems, smoke-control systems and special suppression systems. Efficiency of their operation largely depends on the correct design, installation, testing, inspection and maintenance.
- **Inspection and Maintenance:** Inspection and maintenance of fire protection systems is of crucial importance since it helps to preserve their reliability. Electrical installations, alarms, detectors, emergency lighting, extinguishers, hydrants, pumps, sprinklers, smoke control systems, fire doors, escape routes and emergency communications have to be inspected and maintained regularly. Otherwise, a fire protection system will not operate properly.

In general, the fire safety system will require the combination of passive fire protection, active fire protection, maintenance, and good management practices. The presence of fire safety equipment is not enough without proper maintenance, testing, and implementation of correct emergency response procedures.

6. EMERGENCY PREPAREDNESS AND EVACUATION

Emergency preparedness is the organizational measures put in place to ensure that occupants remain safe prior to, during, and right after a fire. An effective emergency plan outlines duties, communication process, evacuation routes, muster points, emergency contacts, help for vulnerable occupants, and coordination with emergency services [21]. Effective preparedness ensures that in addition to fire protection systems, there are proper measures in place whereby occupants know how to behave in an emergency situation. The evacuation plan must tailor to the specific building, taking into account parameters like building height, building arrangement, occupancy, occupant density, stairway loading, smoke flow, and evacuation routes. Figure 1 below presents the interdependence between hazard recognition, risk evaluation, risk reduction, emergency preparedness, evacuation, response, and continuous improvement.

Figure 3: Emergency Preparedness Cycle [22]

Fire drills and training are critical elements of emergency preparedness since individuals can behave differently during an actual fire situation compared to normal circumstances. The training program should ensure that occupants and staff members have adequate knowledge of the procedures of alarms, escape routes, communication, assembly areas, and their duties. The fire drill should be able to examine evacuation times, occupant awareness, choice of route, communication, the performance of staff members, accessibility, and decision-making. Studies have also noted the growing interest in using virtual reality, augmented reality, and other immersion technologies in training individuals for fire evacuation exercises, although there is need for standardized testing to measure the effectiveness of these approaches.

7. HUMAN BEHAVIOUR AND FIRE EVACUATION

Human behaviour forms part of emergency preparedness since occupants react differently to a fire emergency. For instance, some of the occupants will take their time before evacuating the building, gather more information about what is happening, gather their belongings, investigate the cause of the alarm, help other people or think the alarm is just a drill. This means that the evacuation time involves not only physical action but also the aspect of decision making and human behaviour. Risk perception, prior experiences, knowledge about the building, the perceived severity of the emergency, and assurance about evacuation routes will affect decision to evacuate.

Table 3: Summary of Selected Literature on Fire Risk and Emergency Preparedness [23]

Reference	Focus of Study	Key Findings
Ricci et al. (2021) [24]	Natech events	Highlighted combined natural and technological risks.
Khanal et al. (2022) [25]	VR and AR in disaster management	Supported emergency training and preparedness.
Ma & Wu (2020) [26]	BIM-based fire emergency management	Integrated occupant behaviour into evacuation planning.
Munasinghe et al. (2024) [27]	UAV–UGV collaboration	Highlighted potential for emergency monitoring and response.

Proper communication plays an important role in making sure that there is prompt coordination of efforts in times of fire emergencies [28]. The alarm system must give immediate warnings, and trained staff must assist people to use the safe exit points whenever necessary. Forms of communication may include fire alarm systems, warning lights, voice evacuation systems, public address systems, emergency messages, floor warden communication, digital communication systems, and direct communication with the emergency responders.

8. CHALLENGES IN FIRE RISK ASSESSMENT AND EMERGENCY PREPAREDNESS

In spite of the development in fire safety engineering, building codes, and emergency management practices, some technical, organizational, human, and managerial difficulties persist and hinder fire safety in commercial buildings [29]. Some of the major problems that have been found in the literature are listed below.

- **Compliance versus Actual Safety Performance:** It might be noted that though the building may satisfy the regulatory requirements on inspection, but due to inadequate maintenance, blocked exits, failure in the alarms, changes in the occupancy, and unauthorized modifications, it could be deficient in its operations.
- **Maintenance Deficiencies:** Fire protection systems must be inspected, tested, and maintained on a regular basis. Improper maintenance of the alarms, sprinklers, pumps, emergency lighting, fire doors, extinguishers, smoke control systems, etc. will affect the reliability of the system in case of an emergency.
- **Training Deficiencies:** If there is lack of adequate training for the employees, security personnel, and emergency staff, it will lead to delayed alarm activation, improper extinguishers operation, improper communication, and ineffective assistance in evacuation.
- **Human Behaviour:** Human behaviour during emergencies is unpredictable. There are several reasons that determine the level of evacuation success; these include risk perception, decision-making, social influence, information seeking, experience, and knowledge of the building.

- **Complex Design of Building:** High-rise buildings, atriums, underground parking, mixed-use buildings, HVAC systems, open-plan spaces can be complex to deal with regarding detection of fire, smoke movement, firefighting and evacuation.
- **Lack of Integration of Risk Assessment Tools:** The current fire-risk assessment tools may examine each of the safety aspects separately without incorporating all aspects such as building features, occupant behaviour, fire consequences, emergency response, management, etc.
- According to the literature review, fire safety in commercial buildings depends not only on complying with the required regulations [30]. It is vital to conduct timely maintenance, provide proper training, make a realistic analysis of human behaviour, utilize appropriate risk assessment techniques, coordinate the efforts of the organization, and monitor activities.

9. CONCLUSION

In conclusion, it is evident that the safety of commercial buildings against fire involves an integrated process of risk assessment, risk prevention, protection, emergency preparedness, evacuation plans, and continuous risk management. In general, there are different types of risks associated with commercial buildings. They include risks related to electrical systems, use of flammable materials, cooking and heating activities, buildings' designs, smoke movement, human Behaviour and maintenance problems. Systematic fire risk assessment helps detect such hazards, while passive and active fire protection will decrease the spread of fire and increase the safety of its occupants. Nonetheless, all these processes should be supplemented by constant inspection and maintenance, good training of employees, good communication during emergencies, realistic drills and evacuation plans, which depend on the particular building. Risk perceptions and human Behaviour are also very significant in terms of successful evacuation. In addition, there are some other challenges connected with regulatory compliance issues, poor maintenance, lack of training, complexity of building design, lack of integration of risk assessment approaches and coordination.

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