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REVIEW PAPER

The need to identify challenges for the fire safety evacuation in high-rise buildings in India

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Abstract

High-rise buildings have become a vision of the future as cities grow vertically in developing nations like India. High-rises are a practical by-product of modern times and are defined as structures built higher than 75 feet or 7 to 10 stories in India. In the last ten years, many Indian metropolises have become centers for the construction of new high-rise structures, with Mumbai unquestionably at the top of the list. Mumbai has India's greatest concentration of high-rises, with nearly 200 skyscrapers and 12,000 built high-rise structures. Aside from having the highest rises overall, it is also noted to have the highest rises currently under construction. The study examines the status of fire safety requirements in high-rise buildings, considering the planning, specification, and time required for evacuation in the context of India. These towering structures are mostly residences. High-rise buildings used to be primarily driven by the focus on their structure, but evolving trends and developments in construction techniques give architects and designers more creative and architectural freedom in the current times. Such emphasis on creative and architectural aspects at times results in compromising with the safety aspects of these high-rise buildings, for instance, fire safety. Three case studies are presented to map existing fire safety, its functioning, and safety measures during the evacuation in the context of the Indian scenario. A critical requirement ensures fire safety services enable building occupants to behave safely on their own during fires. The current legal requirements for fire safety fail to deliver adequate support to people during emergencies. The current study's findings support these proposed recommendations that will create substantial effects on public fire safety programs by raising awareness about high-rise building fire risks and their causes and effects. The legislation needs improvement to explicitly regulate fire safety in high-rise buildings while establishing regular inspection requirements and designing evacuation and firefighting exercises with building occupants.

Keywords: High-rise buildings, Fire safety, Challenges, Human behavior, Building efficiency, Evacuation.

Introduction

Three qualities define high-rise structures: Complex construction structure with high height, numerous floors, and podiums; Complex functions with high people density; Wide range of uses, including residences, hotels, offices, stores, and so forth. There are many combustibles and a lot of fire hazards (like a lot of combustible decorative materials like a combustible roof, plastic wall covering, wallpaper, curtains, and so on). A fire can rapidly spread. Many vertical shafts, including cable shafts, pipe shafts, air passageways, and elevator shafts, can be found in high-rise buildings. In case fire separation is not set up properly, they will turn into lofty chimneys—that is, they will serve as pathways for fire to spread—especially in luxury hotels, extensive buildings, libraries, offices, and other high-rise structures. There is a lot of combustible material present, so when it catches fire, combustion will spread rapidly and be intense.

National Fire Protection Association (NFPA 2012), high-rise buildings are defined as structures exceeding 75 feet (approximately 23 m) in height when measured from the lowest fire department vehicle access point to the floor of the highest accessible story. (Petersen, 2019). The National Building Code of India-2016 defines buildings exceeding 15 meters in height as high-rise buildings regardless of their occupancy type (Misra, 2012).

Visions of Future Cities and Tall Buildings

As the cities are growing across the sphere, vertical growth is evident, as horizontal growth has limitations due to space scarcity. Even vertical farming is envisaged as the future of the cities. The future cities will not be envisioned as low-rise

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but as three-dimensional skylines merged with horizontal built forms (Council on Tall Buildings and Urban Habitat, 2012).

- High rise contributing to the city's image
- The average height of high-rises across many Indian cities is 30mts
- Changing regulatory measures
- A major shift from commercial to residential high-rise

Cities throughout India have seen a quick expansion of their high-rise building densities. India stands as the second most populous nation worldwide together with its urban centers. The data in Figure 1 shows that most Indian cities have buildings exceeding 100 m in height. Metropolitan regions in the nation are experiencing a surge—both in cost and kind—as a result of densely populated cities, a surge in trade operations, commercial activities, and urban growth. The purpose of use of these high-rise buildings is represented in Figure 2. Tall buildings offer the best solutions for resolving such an issue because they expand vertically through constructed structures and accommodate more people than they do by developing horizontally. Property and land are starting to become scarce and expensive in these areas.

In regard to the discussion on High Rise Buildings in Indian cities, the concept of FSI also needs to be discussed. The Floor Space Index is referred to by the acronym FSI. The Floor Area Ratio is an alternative term for it. This is the largest

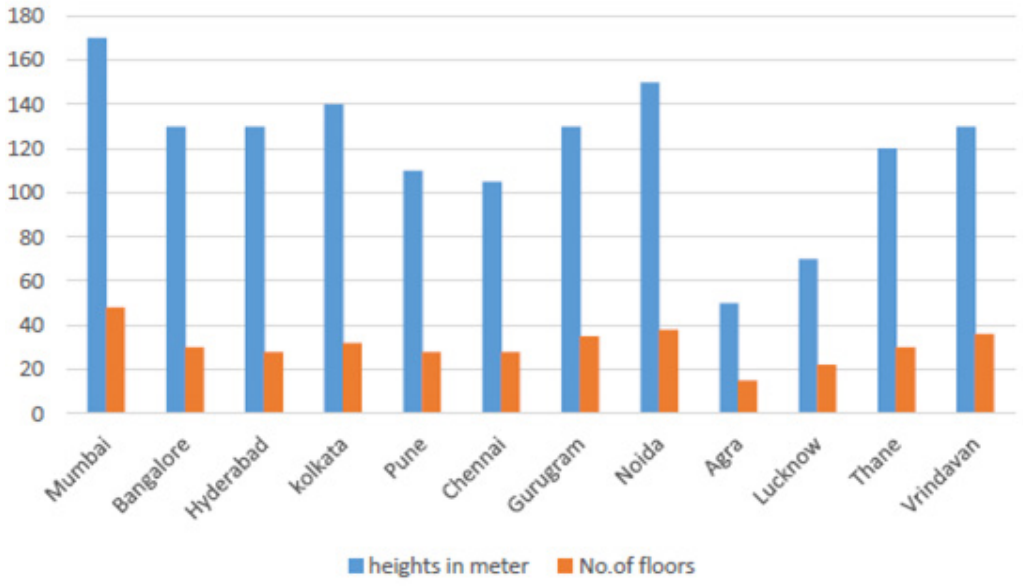


Figure 1: The graph indicating the average height and the no of floors in Indian cities

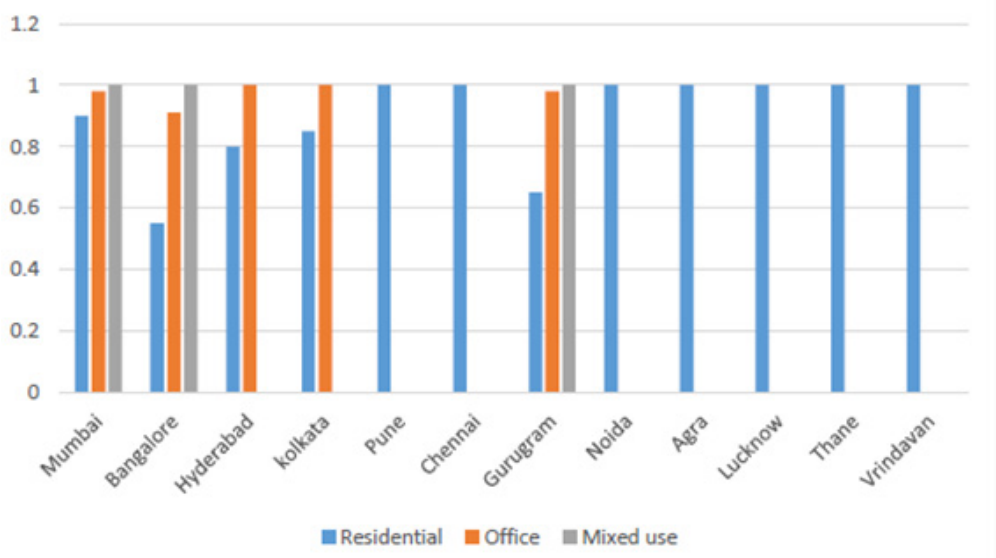


Figure 2: Functions of high-rise buildings in Indian cities

area that a contractor is permitted to construct on a specific piece of property. The state government's municipal officials determine the FSI value, which is based on several variables. It is founded on the city's governing body's bylaws. The size of the plot, the location, the width of the road next to it, the availability of electricity, sewer lines, and water, as well as the type of building—the commercial, residential, place of worship, institutional, among others— all play a role in this decision. FSI in Major cities of India has been represented in Table 1.

The nationwide expansion of high-rise buildings remains limited to specific cities throughout India. The rapid construction of high-rise buildings occurs at only a few locations throughout India. The fast expansion of high-rise buildings stems from three main factors: population growth immigration and the need for urban housing. The cities shown in the graphs demonstrate elevated population distributions between their urban zones and rural territories. Figure 3 demonstrates that all Indian cities except Kolkata show higher population distribution within their inner areas than their outer areas. The high population distribution across inner and outer city areas leads to increased population density in these cities. High-rise housing construction projects started in both inner and outer city areas of these cities during the 1990s.

The construction of skyscrapers remains a new development in these cities. The city of Mumbai stands alone in having buildings that exceed 50 meters in height before the 1990s. High-rise buildings are currently expanding at a fast pace throughout various Indian cities. The data in Figure 4 demonstrates that Indian cities now feature buildings that reach 100 meters in height (Regional Centre for Urban and Environmental Studies, 2016).

Among the 13 selected cities there exist 9 with three or more buildings that surpass 100 m in height. The cities extend their development from central areas to outer regions. Figure 3 provides detailed information about the typical height and floor levels of high-rise buildings throughout Indian cities.

Table 1: FSI in Major cities of India (Bryan, DiMenna, Drysdale, & Beyler, 2020)

Sl.no	*CITY*	*FSI*
1.	DELHI	MAX-4
2.	MUMBAI	MAX 4-5
3.	BANGALORE	MAX 3.5-4
4.	CALCUTTA	MAX-3.5

Figure 4 illustrates the various functions of high-rise buildings throughout different Indian cities. The properties are found inside the core cities of Mumbai, Bangalore, Hyderabad and Kolkata although the elevated structures in urban clusters and satellite towns mainly serve as residential spaces.

Overview of high-rise buildings –Fire safety

The high-rise design and construction pose a variety of life safety questions for the architects and engineers responsible for providing a functional building. Fire safety issues exist in both existing and new high-rise buildings. The life safety of the residents is of the utmost importance in any high-rise building. To achieve complete protection through a single system or procedure is impossible, a synergistic effect of all systems (i.e., passive and active fire protection systems) and the building design features, and aspects of human behavior ensure safe evacuation. Throughout history, high-rise standards have been applied to many buildings, where it has incorporated the functions that work and kept them safe over the years. As high-rise buildings become more complex, the overlap of all systems becomes more important than before. To recognize and complement the building design or human intervention that complements these advanced

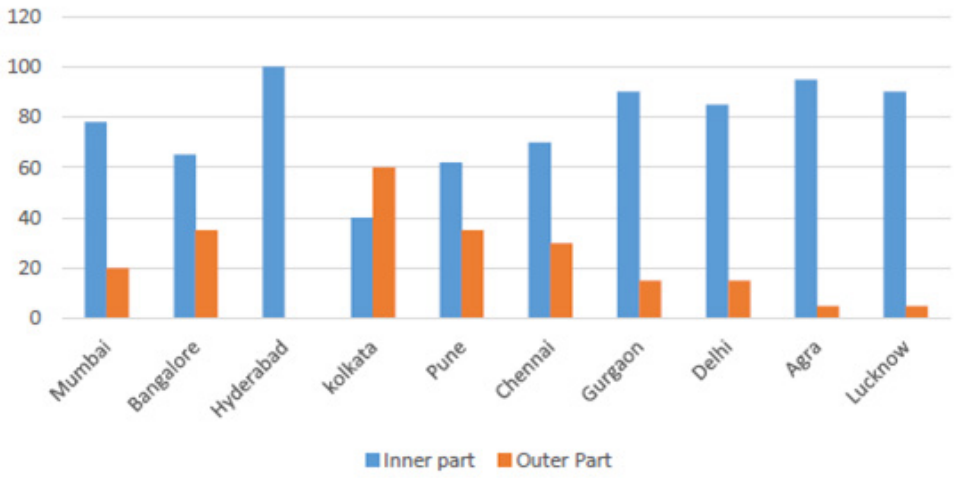
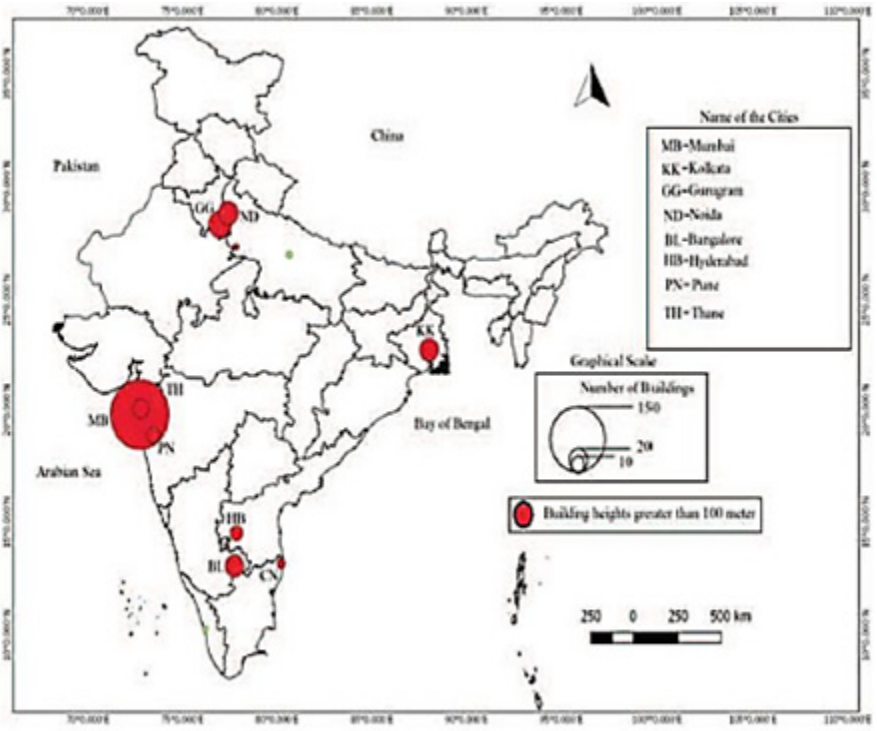


Figure 3: Graph showing the population share between the urban areas and rural regions of the cities



Source: skyscraper center, 2020
Figure 4: Map showing the Indian cities having 100 Meter Height High-Rise Buildings

systems. High-rise buildings are not fundamentally unsafe construction, but they do require additional fire safety provisions, which is not the case with other buildings. An integrated approach adopted with codes and standards should be followed, considering the impact of the structure on safety and how the different fire safety features in the building complement each other to achieve a building's fire safety objectives (Society of Fire Protection Engineers [SFPE], 2012).

Fire safety refers to the four major aspects (Proulx, 2003)

- Prevention of fire
- Stopping the spread of fire and smoke
- Suppression of the fire and
- Quick and safe exit from the place

Identified Evacuation Threats

During the preliminary phase of a fire accident, residents normally have to escape from the building themselves or be saved by others at their adjacent location (Rubadiri, Ndumu, & Roberts, 1997).

After the primary fire phase, the assistance of expert firefighters and emergency treatment can be provided, therefore human behavior becomes an essential element in this phase (Rubadiri, Ndumu, & Roberts, 1997), (Purser & Bensilum, 2001). The moves that residents take are based primarily on their understanding of the situation, the actions taken by using them, and the considerations addressed rather than the actions performed. This behavior of the residents during the flight is called evacuation behavior.

A safe escape route stands as the primary element of fire protection characteristics in built structures while fire safety conditions include preventive measures alongside fire and smoke control fire suppression and safe evacuation procedures. Fire protection policies demonstrate public and political perspectives on societal issues. The "guard-in-region method" or Horizontal Evacuation serves as a fire procedure for specific locations including hospitals where patients remain at their bedsides. This method is permitted by regulations in various countries when residents cannot evacuate effectively. The method requires staff to relocate residents to protected areas within their current floor instead of moving them to different locations. Large fires in certain buildings have proven that complete safe evacuation of burning buildings remains impossible for all occupants.

High-rise buildings exhibit three main characteristics: their extensive vertical height and numerous floors and their evacuation process takes an extended period. The population exists in dense concentrations. The spread of fires and smoke becomes rapid after ignition because open airflow allows unrestricted movement. The combination of these factors creates additional obstacles to escape. Most cities with high-rise buildings do not possess lift-up fire engines yet some developed cities have started acquiring these vehicles. The buildings' elevated height makes it impossible to fulfil necessary safety evacuation standards. The primary disadvantages of evacuating high-rise buildings

include those mentioned previously. The fire proves difficult to extinguish. The wide range of heights in high- rise buildings from tens to hundreds of meters creates difficulties for external firefighting operations. The initial smoke dispersion velocity reaches 0.3 m/s through air convection but rises to 3–4 m/s during fire intensity peaks. A 100-meter high-rise building can spread smoke through its vertical shafts to reach the top floor within 30 seconds at speeds that exceed horizontal smoke movement by ten times. It is challenging to escape. The research by (Pires, 2005), examined the various obstacles that affect fire evacuation in these buildings. Participants reported that inadequate interior design features such as "fire escape and emergency exit deficiencies and unsafe low-quality construction materials" represent structural obstacles that stand as the primary factors affecting residential building fire events and their resulting injuries. Participants reported that building construction safety alongside fire protection standards received minimal attention during their experiences. The rapid spread of fires occurs because of certain construction materials used in buildings. Research participants identified unsafe electrical wiring and equipment as primary fire causes while highlighting major challenges with building energy resources including canisters and gas pipelines. Research participants emphasized that improper storage of flammable liquids in rural city areas creates elevated fire risks which lead to severe damage. Overloading electrical systems occurs when multiple devices are plugged into a single outlet which leads to fire hazards.

Building Evacuation

The study of the evacuation of buildings started in the 20th century (Kobes, 2008), (O'Connor, 2005), which mainly focused on the movement of the people on one staircase and thus the corridors that pass the doors. The researchers, including Pauls, Fruin, Predtetschenski, Milinski, Habicht, and, in particular, Braaksma (O'Connor, 2005) (Sime, 2001), collected detailed information on resident density and travel speed. The current fire approach was seen worldwide. The research produced minimum requirements for escape stair widths together with maximum flow capacity for emergency exits and specific requirements for emergency exit numbers and architectural solutions. The current fire safety measures for buildings focus primarily on technical solutions that disregard typical building usage patterns. Research on how people behave during fire escapes appears to be absent from current studies. The twentieth century witnessed a shift in building security behavior from technical to behavioral approaches. Sime (1999, 2001) developed the resident response shelter escape time (ORSET) model which serves as an example (Sime, 2001), (Bryan, 2002). The theoretical framework unites architectural and engineering elements of building fire safety with psychological and facility management aspects of human behavior during evacuation. The ORSET markers that correspond to occupational risk criteria include Occupational and Job Profiles, Pre-Movement Indicators, Visual Signage Design, Indicators, and Escape Routes (Sime, 2001). Sime considers work as the bond that exists between individuals and their surroundings while he maintains that professional conduct depends on environmental factors. The traditional psychological theory views people through the lens of stable personality traits abilities and personal characteristics. The data implies that physical (and social) environments react differently to each other. People behave based on their situational adaptation and the structural elements of information and opportunities which vary between locations (Sime, 2001).

The evacuation assessment process depends on factors beyond individual traits or building occupancy patterns. The evacuation grade depends on how a building is designed through its floor plan and floor plan and interior design. The probability of survival during a fire depends on fire protection systems such as escape routes and emergency exits. The readiness of these systems depends on two factors: the fire conditions at the location and the state of maintenance and suitability of the fire protection systems.

The connection between human Behaviour and fire

The United States (USA) became the first nation to conduct scientific studies about human fire behavior during the 1950s (Bryan, 2002). The researchers during that period believed buildings would remain safe during fires so they focused their studies on social behavioral patterns related to fire occurrences while neglecting building design elements for safe evacuation. The fire's magnitude directly correlated with how staff members behaved before and during the incident. A survivor of the Arundel Park Fire (1956) recounted how he returned to the building after fleeing to search for his missing relatives (Bryan, 2002). Research on human behavioral factors in fires gained prominence during the 1970s which transformed our understanding of fire safety and led to educational and research initiatives. A comprehensive Canadian study about large office building evictions took place between 1969 and 1974. P. G. Wood executed a comprehensive investigation of fire-related human conduct in English residences in 1972 (Irvine & McCluskey, 2000).

The firefighter conducted interviews with 2,139 people who participated in 952 fires by using standardized questionnaires. Bryan conducted a research study in the United States during 1977 which followed Wood's methodology by interviewing 584 people who experienced 335 fires. The research was divided into two sections with half of the participants located in residential buildings and the other half situated in shops and offices. The research findings demonstrated once more that families frequently return to burning buildings following their first escape. The research revealed that individuals displayed higher tendencies to navigate through smoke and attempt to

extinguish apartment fires. The research findings from both countries with their contrasting cultural backgrounds produced comparable results (Bryan, 2002), (Kobes, 2008).

The current model of fire safety *(Tubbs, 2004), (Graham & Roberts, 2000)*

Building fire safety models in current use focus on design and management aspects because these elements appear in most Western building and fire codes. Fire protection policy contains technical elements alongside social considerations. The number of fire fatalities reflects the level of fire safety that government policies together with their implementation and enforcement procedures determine. Deadly fires spread throughout the world during nighttime hours in residential buildings including hotels and apartments (Kobes, 2008; Tubbs, 2004; Graham & Roberts, 2000).

In addition, fatal fires occurred in buildings used by people who could not escape on their own. In lethal fires in meeting houses, the following factors, or combinations thereof, determine the lethal outcome (Tubbs, 2004; Graham & Roberts, 2000; Graham & Roberts, 2000) high occupancy; Presence of combustible building materials used for the interiors in the building.

Non-availability of emergency exits. Buildings with specific occupant types that experience deadly fires often lead to safety requirement assessments following such incidents. The outcomes from deadly fire investigations together with scientific experiments fail to provide complete assessments of fire safety policy ideologies and assessment roles which leads to limited implementation of current regulations. Such iconic policies deliver absolute security promises despite their extremely low occurrence rates. The green-colored escape route signs serve as a prime illustration of iconic fire protection measures (Purser & Bensilum, 2001).

Law enforcement officials and policymakers focus intensely on the placement of exit signs (green) alongside their pictogram signage announcement systems fire detection systems fire safety plans fire alarms and other elements. The public understands that green signals indicate both safety and permission to proceed because this color has dual meanings of safety and go. People tend to move toward green symbols instead of red ones when a fire emergency occurs. The placement of these green signs ensures visibility during smoke conditions that block exit signs in case of fire. People tend to overlook incident assessment signs during evaluations because they remain unaware of their presence (Johnson, 2005), or choose to disregard them (Johnson, 2005), (Boer, 2002). The assumption that people will begin their building evacuation immediately after detecting a fire through evacuation signals represents a widespread fire safety paradigm in Dutch buildings. But event evaluation (Proulx & Richardson, 2002), (Proulx, 2003), shows it is often not the case. The delay between when someone in the field detects a fire and recognizes its danger results in an extended response time to the fire (Irvine & McCluskey, 2000; Proulx, 2003) (Figure 5).

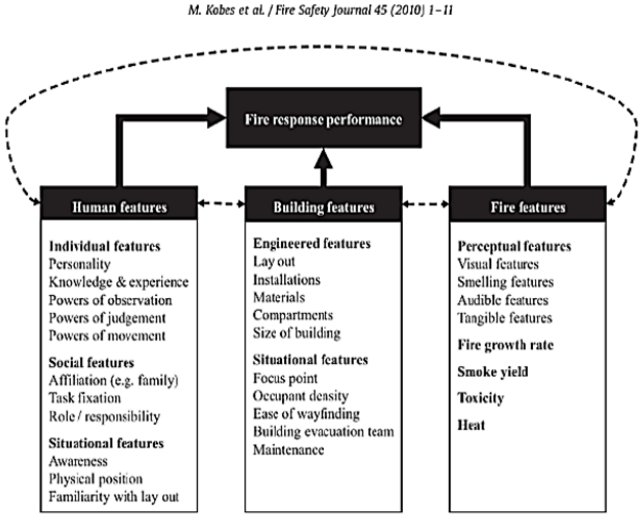
Identified threats in Fire Safety Evacuation in India

The three fire accidents as a sample with the norms for selection are presented as case studies to analyze the fire safety measures present across the cities of India. Among the chosen fire accidents, the death toll was high, and the incidents were devastating in India. The reason for choosing these three incidents of fire safety evacuation is, that the buildings are about 28 m, 32 m, and 80 m, which are locations of significance in these regions. The factors are the building design, the cause of the fire, the fire load, the fire spread, the existing fire safety measures of the building, their efficiency, and the reasons for the failure during the accident.

Case study 1

AMRI Hospital building fire accident. Date: 9 December 2011. Place: Kolkata. Deaths = 94, No of floors: 7 (NDTV. (2011, December 9)

The hospital building has a basement, ground, and six floors above. The openings like the doors and windows are of glass, the exterior finishes include the glazing which is not openable and breakable. The combustible materials on each floor added to the fire load, thus creating thick smoke, fumes, and toxic substances produced by the fire. The fire initially started in the basement, which was used for storing the diesel, there was also the presence of motor oil and wooden furniture which added to the spread of the fire. The reason the fire accident occurred was the fact that the fire sprinklers and the vent opening on top were not provided to reduce the smoke it almost took four hours for the fire personnel to reduce the smoke. The fire spread in the building and the smoke that was caused by the fire was very high.



source: Oberijé *et al*., 2009
Figure 5: Fire response performance model

(A) (B)

Figure 6: (A) AMRI Hospital- -under fire; (B) AMRI Hospital- -Glazed Facade

This picture displays the fire from the basement and the thick smoke spreading from the lower portion, i.e., the basement to the upper floors (Figure 6). The photo reveals the exterior façade glazed. The major reason for the spread of the fire was the form, which is like a cube and the building was without ventilation, the spread of smoke was instant, as there were no openings, making the building very hot and covered with smoke, thus making the evacuation difficult. The patients could not find their way out due to the thick smoke and they suffered from breathing difficulties and suffocation. The lack of provision of firefighting appurtenances, and the no trained housekeeping staff, were the main causes of the failure of fire safety (International Journal of Engineering Trends and Technology [IJETT], 2014)

Case study: 2

Carlton Tower office building fire accidents. Date: 28 February 2010. Place: Bangalore. Deaths - 12, No of floors: 8, (Reddit User. (2023, July 25)

Carlton Tower office building is a multi-storeyed commercial building that has a chain of offices and is situated in a densely populated area. The fire spread from an elevator service cable on the second story through the duct the smoke filled the other floors. The reasons for the fire accident and the poor evacuation were as, the building had a provision of three staircases, which were locked on the ground floor with a collapsible gate and were modified and blocked with additional construction on the middle floors. Missing signage for emergency exists and signs for lifts and stairs were identified as one of the criteria for not using the lift at times of emergencies. The service ducts were overloaded with cabling in an unprofessional way. The wet riser and downcomer system were not working due to a lack of maintenance. The fire detection system was not maintained, and, in a few places, it was covered by the false ceiling and removed a few places. The sprinkler system was removed on a few floors and the existing ones were not found to be working. The extinguisher was missing from most places. The Marking of the escape routes was missing. The public address system was missing. Fire safety plans found displayed at each staircase landing were not to be found. At least 40% of the occupants had to be trained

(A) (B)

Figure 7: (A) Carlton tower-Under fire; (B) Carlton tower-the extent of smoke

in fire prevention and protection which was not addressed (Karnataka State Fire & Emergency Services, 2010) (Figure 7).

Case study: 3

Kamal Mahal fire accidents. Date: 22 January 2022. Place: Mumbai. deaths-9 No of floors:20 (Jansatta. (2022, January 22)

One of the first structures to be built on Carmichael Road was the Kamal Mahal, which was built more than 60 years ago. On a two-acre site with a landscaped courtyard, the seven-story Kamal Mahal and the nearby Anand building both have seven stories. The reason for the fire is unknown according to the sources. The fire load was contributed by the furniture and the other wooden materials for the spread of fire. The residents had made alterations in the building which increased the smoke, the doors of the apartments were to be fireproof, but they had replaced them with wooden decorative doors. The common passages in front of the doors were installed with grills which restricted people from moving from their homes. The duct in front of the lift was

sealed on the terrace. The terrace of the building was locked. The security personnel were not trained to use the

Table 2: Brief of the case studies used in the research

Sl.no	*Criterion*	*Description*	*AMRI HOSPITAL*	*CARLTON CENTER*	*KAMAL MAHAL*
1	Fire information	Type of occupancy	Health care	Commercial	Residential
2.		Location	Kolkata	Bangalore	Mumbai
3		No of floors	7	8	20
4.		The source of Ignition	Storage of Diesel and motor Oil in the basement	Electrical fire from an electrical duct at basement floor	furniture and other wooden materials
5		Fire Material	Common hazard materials	Electrical wiring, cables, fixtures, computers	furniture and other, wooden materials
6		Type of Fire	Thick smoke fire	Thick black smoke, the gases emitted were toxic	Thick smoke and fire
7	Building features	Layout	The building shape of a cube sealed at the center	The glazing on the upper floors	The layout was compact
9		Installations	Not enough	Provided but not in working condition	Not adequate
10		Materials	Use of toughened glass for the facade	The glazing and the materials blocking the shafts	The furniture's rated doors
11		Compartments	Not used efficiently	Few compartments were blocked	Compartments were blocked
12		The building and usage	The building did not have cross-ventilation	There were commercial uses that were not permitted	The corridors were blocked
13	Situational features	Evacuation means	The evacuation means were not designed for the patients	The active fire protection was not working, and the access to staircases was blocked	The escape route was blocked and locked
14		Occupant density	More than the permitted limit	More than the permitted limit	More than the permitted limit
15		Ease of wayfinding	Smoke was thick and hence it was difficult	The smoke was thick and toxic	The way was blocked, and gates were locked
16		Building evacuation team	Very few	The team was not trained	No team
17		Maintenance	Poor maintenance	Poor maintenance	Poor maintenance
18		Remarks	Special fire safety provisions to be looked into for the healthcare	Lack of inspections to identify fire safety deficiencies	It is necessary to design campaigns and programs that would raise citizens' awareness of the risks

(A) (B)

Figure 8: (A) Kamal mahal-Under fire; (B) Kamal mahal-smoke the 118th floor

fire equipment. The threats identified were the modification of the passageways, risers, and alarms not working. Regular checking and maintenance of the fire safety requirements are necessary. Training the people in the fire equipment is required (Guturu, 2016) (Figure 8).

Case studies result with discussion

The lessons learned from the three case studies are the lack of maintenance of the existing passive and active fire protection systems the absence of periodic checking and maintenance by the authorities of the fire protection systems, and the training of the staff and the occupants for fire prevention and protection was missing (Table 2). The surface treatment like the paint's applications using non-combustible materials like the skim coating on the surface, and a spray of LED coating will reduce the spread of fire. To reduce the fire, the load of the combustible materials should be separated from the fire source.

Conclusion

The construction of high-rise buildings in India continues to expand throughout central cities megacities and satellite cities. The important estate markets extend beyond national capitals to various cities throughout India. High-rise buildings typically measure between 50 to 200 m in height which makes fire safety regulations for these structures mandatory. The case studies together with the literature research emphasize that proper risk understanding plays a vital role in enhancing high-rise building occupant readiness for fires (Cvetković *et al*., 2020), (Oberijé, Kobes, Weges, & Post, 2009), yet most surveys participants believe fires are unlikely to occur in the future and would start evacuating before professional firefighters arrive. The territory will experience higher death rates and fire-related injuries among its citizens during building fires. Most people lack knowledge about proper safety valve operation and switch usage as well as fire extinguisher handling and evacuation procedures and other fire safety evacuation elements. Many buildings lack proper fire protection systems while inspections fail to detect these deficiencies which should lead to immediate corrective actions. The study results support developing immediate awareness programs about high-rise building fire risks and their causes and effects. The legislation needs improvement to explicitly regulate fire safety in high-rise buildings while establishing regular inspection requirements designing evacuation and firefighting exercises for building occupants and improving preparedness for women and people with special needs to respond safely to fire situations (Irvine & McCluskey, 2000), (Proulx, 2003). This research presents a summary of existing studies that examine human responses to fire situations regarding building safety. The outcomes summarize key factors that determine resident evacuation during fires based on fire characteristics and people and buildings.

Future work

Future research needs to study additional cultural elements and socio-economic factors affecting fire safety levels while performing qualitative investigations to understand better what drives occupants to take or avoid preventive measures. The research findings have clear scientific and social value because they enhance theoretical and empirical scientific knowledge about fire safety and help decision-makers make more comprehensive fire safety decisions in high-rise buildings.

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