Volume 26 Issue 01, 2023 ISSN: 1005-3026 https://dbdxxb.cn/ Original Research 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 7–10 stories in India. In the last ten years, many Indian metropolises have become centres 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 high 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 crucial prerequisite is that the fire safety services enable independent and adequate fire behaviour of the occupants of the building. In general, it seems that the actions that are now required by law, do not always provide the support that people need during fire accidents. Based on the findings from the current study, the following recommendations have been proposed, which would be significant and would have major implications in public fire safety initiatives: awareness of the risks (causes and consequences) of fires in high-rise buildings. It is also necessary to improve the legislation that would explicitly regulate fire safety in high-rise buildings and provide for regular inspections; design and implement certain evacuation and firefighting exercises with occupants of buildings outcomes are presented as an overview of the critical factors that determine the response of the occupants to fire hazards, namely the fire characteristics, people, and buildings.

Keywords: ***High-rise Buildings, Fire Safety, Challenges, Human behaviour, 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

Submitted: 22/03/2023 **Accepted**: 25/04/2023

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 "buildings greater than 75 feet (approximately 23 m) in height where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story". [1] As per **National Building Code of India-2016,** buildings 15m and above in height (irrespective of their occupancy) [2] can been considered as high rise building.

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 vision as low-rise but as three-dimensional skylines merged with horizontal built forms [3].

- 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

High-rise buildings in cities Indian cities are experiencing rapid growth of high-rise buildings. India, along with all of its cities, has the second-highest population in the entire globe. Based on data represented in figure 1 it can be noted for the majority of the cities in India the average height of the building are above 100 meters. 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 are represented with 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.

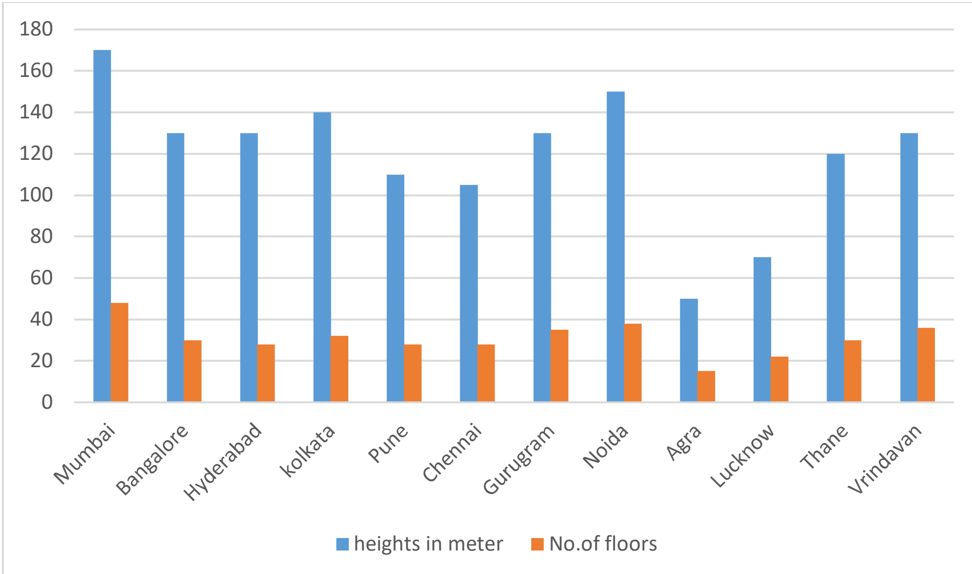


Figure1: The graph indicating the Average height and the no of floors in Indian Cities

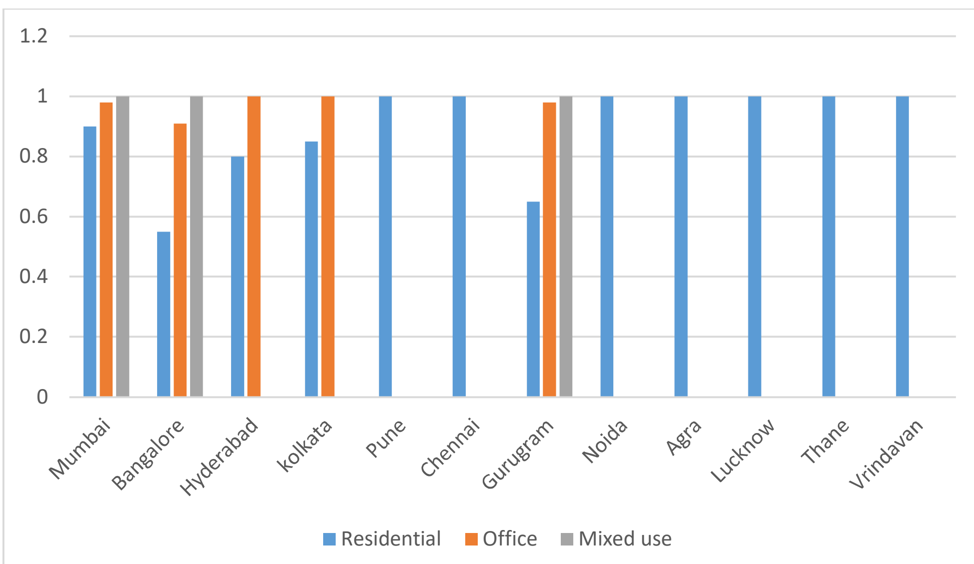


Figure 2: Functions of High-Rise Buildings in Indian Cities

In regards to the discussion on High Rise Buildings in Indian cities, the concept of FSI is also needed to be discussed. Floor Space Index is referred to by the acronym FSI. The Floor Area Ratio is an alternative term for it. This is the largest 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 a number of 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 have been represented with the below provide table.

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

Table 1: FSI in Major cities of India [30]

However, such growth of high-rises is not evident across all the cities in the country. Very few cities are experiencing such rapid development of high-rise buildings across India. The major reasons for the rapid growth of high-rises are the higher population growth, immigration, and demand for housing in the cities. The following Indian cities represented in the graphs have a higher population share in both the urban areas and rural regions. An overview of figure-3 reveals that all (except Kolkata) of the above Indian cities have a higher population share in their inner part compared to their outer part. These cities hold a large population in both inner and outer parts and that makes higher population density in these cities. Therefore, high-rise housing construction has begun both in the inner and outer parts of these cities since the 1990s.

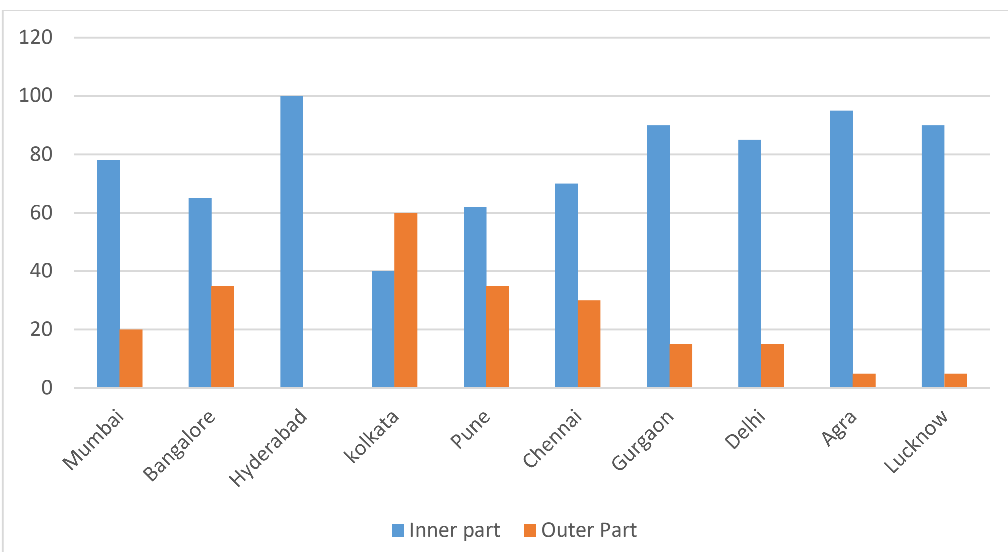
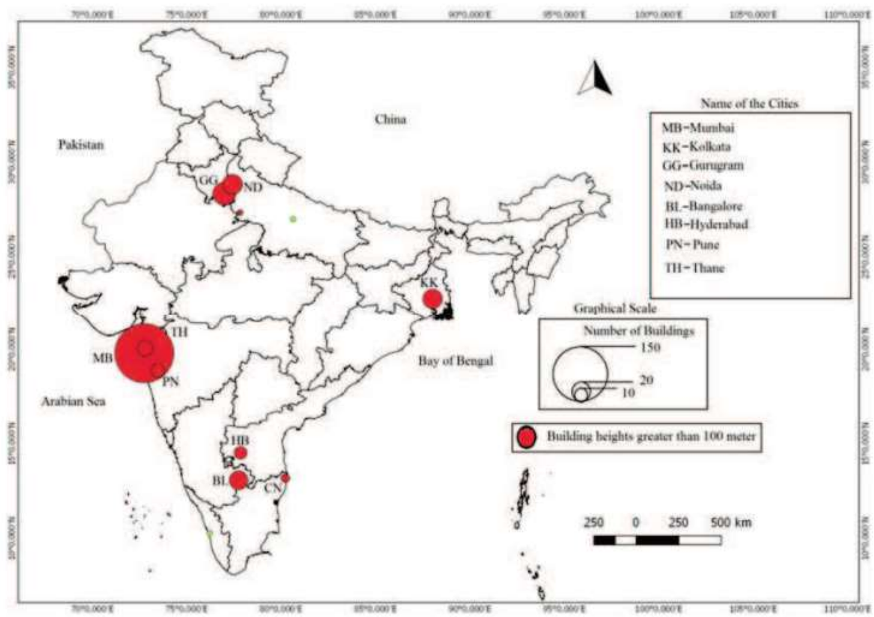


Figure 3: Graph showing the Population share between the urban areas and rural regions of the cities.

However, the growth of skyscraper construction is a very recent phenomenon in these cities. Mumbai is the only city where more than 50 meters of building height exists long before the 1990s. Now high-rise buildings are rapidly developing across different cities in India. Figure 4 shows the Indian cities having 100-meter height high-rise buildings [4].



Source: The Skyscraper Center Database, 2020.

Figure 4: Map showing the Indian cities having 100 Meter Height High-Rise Buildings, [source: skyscrapercenter, 2020]

Out of 13 selected cities, 9 cities have more than two 100-meter height buildings. These cities are spread from the centre to the fringes. However, figure 3 reveals more about the average height and floor of high-rise buildings in Indian cities.

Figure 4 shows the functions of the high-rise buildings across the different cities in India. It reveals that the offices are located within the core cities like Mumbai, Bangalore, Hyderabad, and Kolkata while high-rises developed in the satellite towns or urban clusters located within megacity regions are mostly residential in nature.

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. The fire safety issues ~~on~~ 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 behaviour 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 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. [5]

Fire safety refers to the four major aspects

1) prevention of fire
2) stopping the spread of fire and smoke
3) suppression of the fire and
4) quick and safe exit from the place. [25]

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 [6].

After the primary fire phase, the assistance of expert firefighters and emergency treatment can be provided, therefore human behaviour becomes an essential element in this phase [6,7]. 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 behaviour of the residents during the flight is called evacuation behaviour.

The safe escape route is the most important part of the fire protection characteristics of any built form, fire safety conditions to the preventive measures, controlling the development of fire and smoke, extinguishing a fire and the risk of a short and safe escape. Fire protection policies reflect how people think about the issue of society in the large and political arena. In some circumstances, residents cannot evacuate proficiently as is desired always, so regulations in many countries allow the "guard-in-region method" or Horizontal Evacuation, fire procedure for precise places, including hospitals, where patients are kept at the bedside. With this method, residents are moved to a safe area on the same floor level instead of being evacuated to a different location. Nevertheless, the large fires in some structures have discovered that the safe evacuation of a burning building is not always possible for everyone.

The following are characteristics of high-rise buildings: First of all, there are many floors and a lengthy vertical dimension; additionally, an evacuation would take too long. Second, there is a concentrated populace density. Thirdly, fires and smoke spread rapidly once it takes fire because airflow is unblocked. All of those make escape more challenging. While the majority of cities with high-rise buildings lack lift-up fire engines, some developed cities have purchased a few of them. This is because the height of the buildings prevents them from meeting the requirements for safe evacuation. The major drawbacks of evacuating high-rise buildings are those listed above. The fire is challenging to put out. High-rise buildings can vary in height from tens of meters to hundreds of meters, making it challenging to put out fires from the outside. The horizontal velocity of smoke dispersion is determined to be 0.3 m/s during the early stages of a fire due to air convection, but it can increase to 3–4 m/s during the more intense stages. When a high-rise structure with a 100-meter height catches fire, smoke diffuses through the vertical shafts to the top level in 30 seconds and moves at a rate that is more than ten times faster than smoke moving in a horizontal direction. It is challenging to escape. In the study conducted by [8], the challenges associated with fire evacuation in these buildings were further analyzed. Depending on participants` experiences, unsuitable interior design like the "failure to provide fire escapes and emergency exits, as well as the use of non-safe and low-quality construction materials", are obstacles associated with structural factors that are the most important factors in the structure of residential buildings in the fire events and their related injuries. The safety of building construction and fire protection standards has reportedly received little consideration, according to the participants' experiences. As a result, some construction materials used will enable a fire to spread quickly. Participants in the research stated that unsafe electrical wiring and equipment were among the main causes of fires and that there are significant challenges related to the energy resources used in buildings, particularly canisters and gas pipelines. Some participants stressed the fact that improperly storing flammable liquids at home—especially in rural areas of the city—increased the risk of fires and the harm they can cause. One of the things that can cause fires is plugging too many devices into one outlet and overloading the system.

Building Evacuation:

The study of the evacuation of buildings started in the 20th century [9,10], 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 [10–13], collected detailed information on resident density and travel speed. The current fire approach was seen worldwide. Findings yielded minimum widths for escape stairs, maximum flow capacity for emergency exits, a specified number of emergency exits, and other specific architectural solutions. Therefore, the measures required to ensure the fire safety of buildings are currently mainly technical and take little account of the normal use of the building. Indeed, attention to actual fire escape behaviour seems to have been neglected. In the 20th century, building security behaviour changed from a technical to a behavioural perspective. For example, Sime (1999, 2001) introduced the resident response shelter escape time (ORSET) model [13.14]. This theoretical approach combines aspects of building fire safety (architecture, engineering) and human behaviour during building evacuation (psychology, facility management). Here ORSET markers related to occupational risk criteria are [13]: Occupational and Job Profiles, Pre-Movement Indicators, Visual Signage Design, Indicators, and Escape Routes. Sime views work as a connection between people and their environment and believes that professional behaviour depends on a person's environment. According to the usual psychological point of view, people are seen in terms of (stable) personality traits, abilities and personal characteristics. Still, this suggests that one physical (and social) place may not respond as well as another. That is, people act according to their adaptation to the situation and the structure of the information and opportunities that different places provide [13].

Furthermore, this approach also means that the chances of safe escape do not depend solely on individual characteristics or the "use and occupancy of buildings with people". The floor plan, floor plan and (interior) design of a building can also influence the grade of evacuation. For example, installations with fire protection, such as escape routes and emergency exits, are factors in determining the likelihood of survival in the event of a fire. This readiness depends on the one hand on the type of fire conditions and the degree of fire and smoke development at the place and on the other hand on the suitability and maintenance of these fire protection systems.

The connection between human Behaviour and fire

The first scientific investigations into human behaviour during fires were conducted in the United States (USA) in the 1950s [14]. Researchers at the time assumed that buildings would be safe enough in the event of a fire, so the main emphasis was on the relationship between people's (social) behaviour and the occurrence of fires, and minimal interactions between the building design and safe escape. The outcomes showed that the extent of the fire was related to the behaviour of staff in the building before and during the accident. Additionally, in interviews with survivors of the Arundel Park Fire (1956), a resident who was in the building with relatives entered the building again after first fleeing to search for his members of the missing group. [14]. In the 1970s, human behavioural factors in fires came to the attention of other researchers, redefining our understanding of fire safety and sparking research and educational activities. Then, from 1969 to 1974, a full-scale study of evictions of large office buildings was conducted in Canada. In 1972, P. G. Wood conducted a large-scale study of human behaviour during house fires in England [15]. Using standard questionnaires, the firefighter interviewed the 2,139 people involved in a total of 952 fires. Based on Wood's research methodology, Bryan conducted a similar study in the United States in 1977, interviewing 584 people involved in a total of 335 fires. Half of them involved residential buildings and the other half involved other types of buildings such as shops and offices. Both studies showed (again) the tendency of families to re-enter burning buildings after their initial escape. Both studies also found that people were more likely to walk through smoke and more likely to try and put out an apartment fire. Although the two studies were conducted in two countries with different cultural backgrounds, the results were found to be similar [14,9].

The current model of fire safety

Existing models of building fire safety consider difficulties primarily in terms of building design and management, as they are often enshrined in most Western building and fire codes. Therefore, fire protection policy comprises both technical and social aspects. Government policies and their implementation and enforcement are usually thought to partly control the level of fire safety is known by the number of fatalities in fires. Deadly fires occur all over the world, mostly after dark in buildings where people sleep, such as apartments and hotels [9,16,17].

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 [16,17,18]: high occupancy; Presence of combustible building materials used for the interiors in the building.

Non-availability of emergency exits. Fires that have caused many casualties generally raise questions about the safety requirements of buildings with the types of occupants that exist where deadly fires occur. There is also significant evidence that the results of deadly fire investigations and scientific experiments rarely lead to a full evaluation of the ideologies of fire safety policy and the role of assessments, and thus the adoption and execution of prevailing regulations. The odds are usually so low that such iconic policies often promise absolute security. The escape route signs in green colour are a prime example of iconic fire protection [6]. Policymakers and law enforcement attach great importance to the colours, pictograms, signage, announcement speaker systems, fire alarms, fire safety plans, fire detection systems among other aspects, thus, the location of these signs (green exit signs). Although the colour green is associated with safety, it also signifies "safe" and "go," making it obvious to the general public that they should keep their composure and heed the signals. This implies that in the event of a fire, people will rush to the green symbol rather than the red one. These green signs are usually positioned so that they are visible when the exit signs are obscured by smoke in the event of a fire. However, in incident assessments, people are typically unaware of them [20] or ignore them [20, 21]. Another example of a common paradigm for fire safety in buildings, at least as far as the Netherlands is concerned, is the assumption that when people sense a fire, for example when they hear an evacuation signal, they immediately start leaving the building. But event evaluation [23,24] shows its often not the case. The time it takes for a person in the field to notice a fire and realize its threat, as compared to their usual response time, the response time to the fire is in turn increased[15,24].

M. Kobes et al. / Fire Safety Journal 45 (2010) 1–11

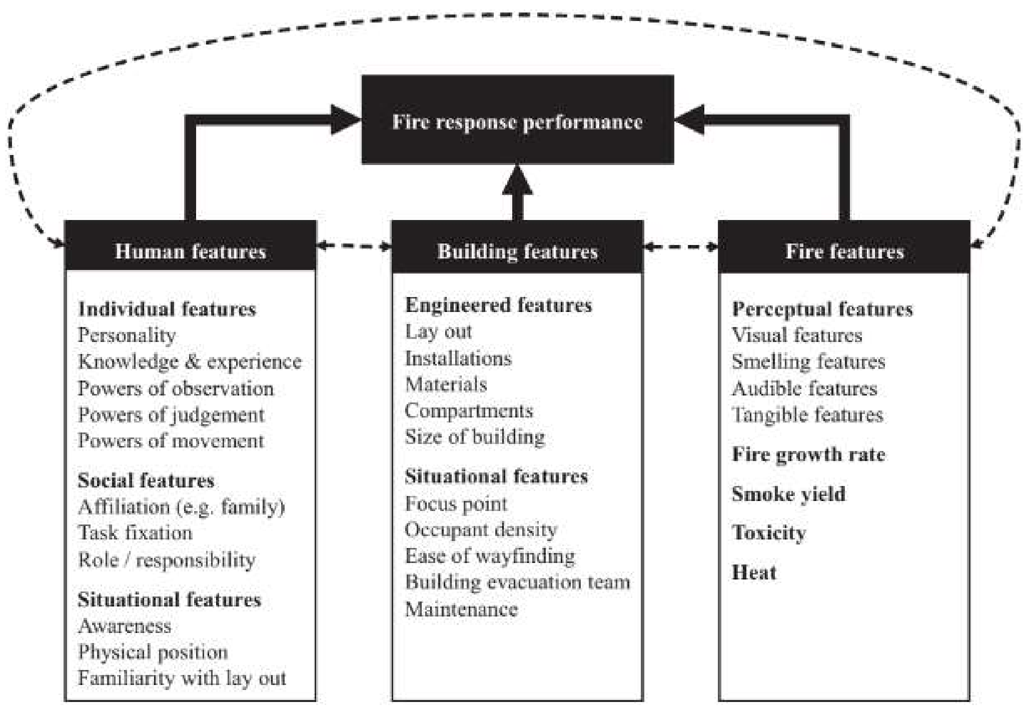


Figure 5: Fire response performance model [source: Oberijé et al., 2009].

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 analyse 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, 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, and 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

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, these were 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.

Photo-1 –AMRI Hospital- -under fire

Photo-2 -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 (spot photo) 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, was the main causes of the failure of fire safety [26].

Case study: 2

Carlton tower office building fire accidents. Date: 28 February 2010. Place: Bangalore. Deaths - 12, No of floors-8

Carlton tower office building is a multi-storeyed commercial building which 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 as. 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 also 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 in fire prevention and protection which was not addressed [27]

Photo-3-Carlton tower-Under fire

Photo-4-Carlton tower-the extent of smoke

Case study: 3

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

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 door of the apartments was 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

Photo-5-Kamal mahal-Under fire ***Photo-6-Kamal mahal-smoke the 118th floor***

sealed on the terrace. The terrace of the building was locked. The security personnel was not trained to use the 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 [28].

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 and 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. 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.

CASE STUDIES					
Sl.no		**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 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 health care	Lack of inspections to identify the fire safety deficiencies	It is necessary to design campaigns and programs that would raise citizens' awareness of the risks

Table: Brief of the case studies used in the research

Conclusions:

High-rise buildings in India are growing rapidly in central cities, megacities, and satellite cities. The important estate markets are not limited to just the capitals and their presence can be seen in various cities in India. The typical height of high-rise buildings ranges from 50-200 meters, where fire safety measures for high-rise buildings become mandatory. The three case studies and the literature studies state the importance of appropriate risk perception in the process of improving the preparedness of occupants for fires in high-rise buildings [31–32], most respondents believe that fireplace is unlikely to happen in the future and that they would begin the evacuation without waiting for the arrival of professional firefighters or rescue units. All this will be related to the increase in mortality and injuries of citizens in fires in high-rise buildings in the territory. Few citizens know the use of appropriate safety valves and switches, fire extinguishers, and how to evacuate, among other factors associated with fire safety evacuation. Another problem is that in many buildings there are no properly installed fire protection systems, and there also are no inspections that would identify such deficiencies and require their immediate elimination. The proposed recommendations based on the study findings are: within the shortest possible time, it's necessary to design campaigns and programs that would raise citizens' awareness of the risks (causes and consequences) of fires in high-rise buildings. It's also necessary to improve the legislation that would explicitly regulate fire safety in high-rise buildings and provide for regular inspections; design and implement certain evacuation and firefighting exercises with occupants of buildings; improve the level of preparedness of women and people with special needs for proper and safe response in situations in which a fire occurs [33]. This paper provides a summary of the available literature on human behaviour in the event of fire about building safety. The outcomes are presented as a summary of the critical factors that determine the evacuation of residents in case of fire mainly dependent on the fire characteristics, people, and buildings.

Future work

In future research, it's necessary to examine other cultural and socio-economic factors influencing the level of fire safety, also as to conduct certain qualitative research that would look more deeply at the factors that influence occupants to take or not take preventive measures.

The conducted research has undoubted scientific and social implications, which are reflected in the improvement of the theoretical and empirical findings of scientific knowledge in the field of fire safety, but also in helping decision makers to consider different dimensions of fireside safety more comprehensively in the high-rise.

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