# Evacuation Methods During Fire in High-Rise Buildings: A Review


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**Abstract** High-rise buildings possess many unique challenges when compared with other low-rise buildings like complexity in evacuation, smoke movement, fire controlling, etc., because of its structure and population density. The literature review of the fire evacuation occurring in the high-rise buildings is being done with the objective to determine behavioral patterns and different aspects that affect the efficiency of the evacuation process. Current methods and strategies, which are currently in use, are comprehensively analyzed. Both the human behavioral patterns and strategic techniques put into practice are included. Various categories of building types are being considered, namely health care facilities, residential buildings, and office buildings. The analysis of egress elements includes the use of elevators, stairs, and other aids of escape like sky bridges, choppers, etc. The use of building and the population residing within the building affects the effectiveness of the egress elements. The effectiveness of various evacuation strategies, which are put into practice, depends on the flexibility of different egress components. The study also involves the effects of fatigues during evacuation and effects of building height increase. The evacuation strategies impact on the staff response, group response and how the physically disabled persons are taken into consideration.

**Keywords** High-rise building · Evacuation · Fire · Safety

## 1 Introduction

According to "National Fire Protection Association" buildings which are greater than 75 feet are considered as high-rise buildings. High-rise buildings can be categorized based on infrastructure and population as office, residential, and health care facility buildings. Building type and its use is essential for the prediction of possible behavior of the people during the fire so that adequate fire safety design can be provided [1].

Evacuation dynamics study requires detailed investigation on infrastructure of the building and also the occupants of the building should be considered, e.g., physical

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capacity of the population under consideration, number of children, familiarity of occupants with the environment, etc.

High-rise buildings have several issues during evacuation, rescue, and fire-fighting operations due to its complexity. In order to mitigate these issues additional life safety measures are needed along with the bare minimum requirements by the existing building codes [2].

International guidance such as NFPA101 (US) gives adequate data for the designing of the egress elements for applications in high-rise buildings. But information regarding behavioral issues during the evacuation process is also needed. Recommendations specific to the type, use, and occupancy of the building are necessary. National committees such as Bureau of Indian Standards (Chapter 7: Fire and Life Safety of National Building Code 2005, India) and also many international committees have given dedicated recommendations [3].

Researchers are giving more importance to fires in high-rise buildings than others because by virtue of the size, population, and other characteristics the number of fatalities can be very high for a fire emergency in high-rise building. High-rise building fires were a concern for the safety committees from 1960s itself. Those committees discussed majorly about basics of evacuation strategies, exit stair width, Evacuation time, etc. The need of providing efficient access and egress, need of studying the relationship between infrastructure and human behavior, etc., came into limelight after the World Trade Centre attack in 2001 [4, 5].

Also several other questions regarding the use of egress components, design of buildings according to the emergencies, emergencies to be considered during the design phase, etc., came along. The main difficulty in answering these questions is unpredictable nature of human behavior. Also every aspect of the evacuation process has to be studied for giving specific recommendations [6]. So study is being done on different types of egress components and egress strategies. Special emphasis is given to vertical transport and use of elevators for evacuation procedure [7].

## 2 Objectives

The study involves not only human behavior but also the egress methods used in building, i.e., both horizontal and vertical egress constituents by the use of egress strategies.

The main objectives are:

- To determine the important aspects that affect the behavior of residents during the occurrence of fire in the high-rise building and scope areas for further research.
- To assess the existing procedures and methodologies being adopted in the evacuation procedures in high-rise buildings.

The targeted audience of this review will include all the members who are part of the design planning and efficient functioning of the evacuation systems like architects,

fire, and safety engineers along with safety officers. This review involves the study of human behavior along with evacuation models based on the type of building [3, 6, 8].

## 3 Methodology

The study data was retrieved from various journals and publications and the data analyzed could be divided into two groups [9]:

(i) Behavior of humans during fire evacuations in high-rise buildings.
(ii) Egress elements and action plan taken during evacuation.

## 4 Limitations

The review paper mainly mentions the issues regarding evacuation and human behavior during the fire. Study involves mainly the buildings like office, health care, and residential buildings. Majority of the fires that occur are of high-rise buildings even though other structures like ware house, assembly halls, recreational buildings also possess the same type of issues [4].

## 5 Outline

Current problem and objectives are described in the initial part. Key factors in the succeeding part are regarding the various uses of high-rise building are found out, and thirdly it represents the issue regarding the usage of different egress components. The egress components constitute elevators used for evacuation during emergency, sky bridges, and other methods like chopper evacuation. The next part involves the analysis of the methods used in evacuation of high-rise buildings. Evacuation lifts and staircases should be used along with egress systems.

The action plan suggested are complete evacuation, staged evacuation, retarded evacuation and defend in place. Partial evacuation can be considered as the sub-category of complete evacuation. The problems regarding the evacuation of disabled people are also explained. Further, the paper provides the areas for future research and the topics for investigation [6, 7].

## 6 Behavioral Problems Regarding the Building Using

The group of building types that have been discussed are Health care buildings, Residential buildings, and Office type buildings. The type of building and its use has

a major effect on the egress capability during the emergency such as occupancy in the building, training received by the population, the number of staff present and the type and number of firefighting systems installed in the building.

It is also important to study about various egress methods to be put into practice. For example, any person with physical disability may take more to evacuate with intermediate breaks in between hence increasing the evacuation time needed [4].

## *6.1 Office Building*

Considering the design aspect of office floors, the method of compartmentalization for controlling the fire is limited. The occupants are often trained and made prepared to evacuate through mock drills. The occupants must be liable to themselves. The evacuees sometimes will be more accustomed to use the emergency elevators if they are in place. Those firefighting systems, which are properly maintained, might be some time equipped with fire alarms. Sometimes those staff members who are specially trained in firefighting may facilitate in evacuation [10].

## *6.2 Residential Building*

The characteristics associated with these types of buildings are completely different from design aspect and the number of occupants within the building. The occupants may not be always alert, they might be sleeping or not in dressed up state thus delaying the process of evacuation. As per NFPA the pre-evacuation time required in such buildings are usually higher than other types of buildings. Reasons that delay the evacuation may be emotionality to the structure and the components within the building may cause the person to reenter. The information about the emergency may be communicated slowly due to compartmentalization and communication systems available [4].

The occupants within the buildings may be familiar to their home surroundings but not to the hotels in which they will be staying for short terms. The number of occupants in the buildings may be transient that may lead to difficulty in adaption of escape routes during fire. The compartmentalization may provide defend in place method and the safety officers may consider those options also [11].

## *6.3 Health Care Building*

These buildings should be given proper importance as it involves people with permanent/temporary disabilities and mobility impairments. Even though there are number of staffs in such facilities considering the number ratios with respect to patients due

to which they are not able to perform the rescue operations very efficiently. The factors to consider will mainly include the long distance for traveling, fatigue, path findings, and evacuations vertically. These factors demand the need for further need in more effective egressing strategy. Hence, the training of the staff for the emergency procedure becomes very important [12].

To summarize the effect of building design types on behaviors of people:

- Office Building: Represent large open floorings where compartmentalization possibility is very less, the people present should be prepared to undergo evacuation. Firefighting should be properly maintained and adequate staff should be available.
- Residential Building: Needs longer pre-evacuation durations and sometimes compartmentalization might be present.
- Health care Building: People with disabilities are present, training of staff members is important, and compartmentalization of the area might be available.

## *6.4 Egress Components*

The evacuation from high-rise buildings during fire emergency can be a complicated process and it depends upon the features of vertical egress components. The designing of egress components must consider the factors such as size and type of the population in the buildings, also their possible behavior. The main issues regarding the use of stairs, elevators, and sky bridges during evacuation are discussed here [13, 14].

## *6.5 Stairs*

The primary and traditional method used for the evacuation process is stairs. The general factors such as length and width of stairs, no of stairs, specific features such as the slope, impact of behavior of the people are investigated to provide various methods for stair design. Stairs can be designed considering safe evacuation calculations for the largest occupied floor or as in case of Staged evacuation it can be designed for the simultaneous evacuation of predetermined number of floors. Structural design recommendations for the egress design of stairs are given in the building codes such as International building code (2009). Even though the structural criteria are fulfilled, behavioral-related matters such as behavior in group, behavior of people in panic situation, motivational levels, etc., should also be considered. Gender, type of people, etc., influence the evacuation. Experimental studies were noted, in those cases women and children were given the priority while evacuation, by the male groups [15].

One of the important factors to be considered during the evacuation through staircase is the stream of flow from different floors that might meet each other at some stage. The impact of these merging can affect the total evacuation time, number of

casualties, etc. To enhance the efficiency of flow during the evacuation, floors must be connected to the base of the facing side of the incoming stair.

An extra delay of evacuation process can happen due to fatigue of the people during the process. The people rushing for evacuation may slow down due to the stress and fatigue and they might take rest for some time. This factor depends upon the physical ability of the people. As the physical ability of people is decreasing gradually, this problem can become more evident in the near future [16].

People who are physically challenged have to be considered separately. They might take extra time, as they possess various difficulties in using the stairs. These people may require aids and assistance for safe evacuation. So the time required for the reach of assistance also has to be considered. The disability can vary from person to person so the time required also varies. Suitable design considerations have to be taken initially itself for the safe evacuation of these people.

Other factors such as counter flows, lag in initiation of the evacuation process, the firefighters who might intervene the evacuation process need to be considered [10].

## *6.6 Elevators*

Researches from 1930 have itself studied the usage of elevators for evacuation process. There were always contradictory opinions about the usage of elevators for evacuation. The old concept of avoiding the usage of elevators for emergency evacuations is now a day discarded because of the need for faster evacuation in tall buildings. The elevators are also extremely helpful to people who are physically challenged as the use of stairs is challenging for them [4].

From the design point of view, there are many problems in using elevators as evacuation media. As the space available in the elevators is limited when several people try to evacuate simultaneously it may create congestion. When the elevator moves suction of smoke is an issue as negative pressure is created. The smoke, flames, etc., entering the elevator is extremely dangerous. The special requirements of the evacuation elevators such as emergency communication system, earthquake protection, water resistivity, and emergency power must be implemented. Special care must be taken while setting the pickup area. Pick up floor should have enough space to accommodate large number of population to reduce the rush [17].

The ASME which has the responsibility of elevator codes studied about the effectiveness in usage of elevators for evacuation. In this study, special emphasis was

given to human behavior. While designing the egress strategy involving the elevators, behavioral factors should also be considered. Factors such as the promptness of people to use elevators during the high-pressure situation should be taken into account [6, 17].

## 6.7 Sky Bridges

Sky bridges are horizontal evacuation technique. Sky bridges can be used as evacuation strategy if the building consists of at least two towers. The towers can be interconnected aerially for evacuation from the fire area. This system is now used as evacuation strategy in many parts of the world. A good example is Petronas towers in Malaysia [18, 19].

The effectiveness of the sky bridges depends upon several factors such as the type of construction, height of the building, etc. But still it has benefits such as decreasing the rush for vertical evacuation, reduction in travel distance, etc. Evacuation strategy adopted also plays a role in the effectiveness of the sky bridge. The sky bridge must be located such that the people from both top and bottom floors have easy access towards it. The population of each floor also can be considered for deciding the position of Sky Bridge. Studies are going on about using the sky bridge as a combination strategy with other egress components [18].

## 6.8 Refugee Floor

These are floors to hold the occupants of the building during the emergency. It has several uses such as.

- Evacuees can take rest at the refugee floor to avoid fatigue
- It can serve as command point for rescue team and a firefighting base.
- It can be used as pick-up floors.
- Physically challenged people can get adequate assistance.
- Injured people can be given with first aid facilities.

Overcrowding, fear of people to stay in the affected structure for longer time, Behavioral issues of evacuees, under-utilization, cost effectiveness, etc., are the factors that can lead to the failure of refugee floor concept [20, 21].

Alternative means of escape such as use of helicopters for evacuation can be considered. International regulations such as Indian Fire and Life Safety Code (BIS 2005) give the mandatory requirement of helipads in high-rise buildings. Air turbulence, thermal updrafts, etc., make this type of evacuation too dangerous. Other alternative means are the use of parachutes, ropes, transferrable temporary elevators, etc. [20].

## 6.9 Egress Methods

Firstly, the proper design of the egress structures should be done so as to attain adequate safety level in high-rise buildings. Relocation methodologies have a major role in the designing of safety systems. Efficiency of evacuation depends on moderate density and speed. While an emergency has occurred in high-rise building mostly the evacuation happens downward but there will be situations in which it won't be possible due to unfavorable situations in lower floors, in such cases evacuation from the top or roof floors would be required [22].

But there are many difficulties in such rescue operations of the occupants which might require choppers and other extra occupants help to move up the ladders. This method of helicopter evacuations is very rarely put into practice because of the air turbulence that gets developed which affects the smoke generation within the building. Secondly, the people who could be evacuated by a single process is very less compared to the total people present on the roof and lastly issues regarding the mobility of people like fatigue and disability [23].

Egress strategies used in such buildings can be groups mainly into complete evacuation, staged evacuation, defend in place, and retarded evacuation. These strategies mainly depend upon the number of people living, staff/members present, expected scenario, and hazards that occurred.

### 6.9.1 Complete Evacuation:

In this method, all occupants present in the building are immediately evacuated to the assembly area of safety. As per the case study of WTC attack where the complete evacuation had occurred. The huge number of residents present in high-rise building can cause large density at the path of escape. It will be mainly depended on the type of building. Complete vacation may be initiated either by fire service dept. or due to spontaneous behavior of the people. Various case studies and data have been analyzed in order to understand the human behavior during fire [23].

The spontaneous behavior often leads to the avoiding of defending in place strategy due to the frustration developed in high-rise buildings due to lengthy walking distance to assembly area. Next problem airing in high-rise buildings is that sometimes the population living may not be directly exposed to the hazard. This may be because of compartmentalization vertically and structural size. Increase in time during evacuation may be due to the merging of the escaping people's pathways. As a result, faster evacuation will happen when the time needed for evacuation is reduced and the merging of pathways doesn't happen [10].

### 6.9.2 Staged Evacuation

These methods are used when the single-stage complete evacuation cannot be done practically. In the method of staged complete evacuation, people will be instructed to stay within the building for specified time to make the evacuation optimized. This strategy is considering the concept that the people in the important critical floor levels and nearby areas will be given more priority. This method is used to decrease the congestion that will happen in the egress systems during evacuation. The compartmentalization of buildings do play an important role in controlling the fire emergency situation [24]. The people within the compartment of fire need to undergo evacuation while the remaining people need to undergo evacuation only if necessary.

The efficiency of these strategies will depend upon the firefighting systems installed within the building, training level of the staff members, and the communications means available within the building. While an emergency of fire has occurred on a floor people living within the floors above and below including the one under fire should be relocated. And also they should empty that floor and move to three or four floors below and wait for further instructions [25].

### 6.9.3 Defend in Place

In this method, the occupants residing in the building are supposed to stay inside, shut the door, and wait for rescue members to arrive. This strategy has been initially adopted for the rescue of physically disabled people due to their mobility issues. According to studies, this method is the best approach during fire emergencies in high-rise buildings. The characteristics and conditions of building design and people that affect the effectiveness include:

- Building floor levels, if it is above 6 floors then time needed for low-rise buildings is less.
- Residential buildings should have firefighting systems available.
- The buildings that are made of non-combustible substances.
- All the alarms and monitoring systems are in places.
- Effectiveness of communication systems.

### 6.9.4 Delayed Evacuation

This kind of evacuation occurs when the people who are ready to evacuate are temporarily awaiting the refuge area. It's mainly adopted to evacuate people with physical and permanent disabilities since they need an aid of external person to reach the safe area. Another consideration to be taken is that these people cannot use the stairs properly so further need will be required where there is escape through the stair or egress systems [26].

Hence considering these aspects this strategy can be mainly used in high-rise buildings with majority of such people like health care buildings. Space constraint also comes as an important factor for evacuation. In order for the evacuation to be mostly successful, there should be intermediate refugee floors for providing safe areas for people with disability where the temporary refuge areas provide a sense of comfort. Hence, temporary refuge areas are necessary for specific building which involve people with physical disabilities [26].

## 7 Conclusion

This paper is a literature review on high-rise fire evacuation techniques, egress components that can be used at the time of emergency and the human behavior with its impacts on fire evacuation. Three types of high-rise buildings were considered—Office, residential, and health care facility buildings. Human behavior has a major role to play in the effectiveness of egress strategies and proper usage of egress components. Further studies in the field of fire evacuation should include the effect of fatigue of people, dynamic behavior of groups, faster evacuation techniques, improving the use of refugee area, etc., in fire evacuation.

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