

Evaluation of Fire Protection systems in Residential High-rise Buildings for Evacuation Optimisation- A Case of Bengaluru

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Abstract: Significance of the research- Among different types of occupancies, a Residential high-rise building presents a more significant challenge to fire protection due to its functionality, complexity, and economic value.

Objective of the study- The key objective of the present paper was to examine the situation of physical (as opposed to non-physical) fire protection systems in randomly selected Residential high-rise buildings in Bengaluru for Evacuation optimization.

Methodology- Methods used include Physical observation, document review, and interviews. A multi-attribute evaluation model/approach was applied to establish the sufficiency or suitability of fire protection systems in light of NBC-2016 [1] and Bangalore Byelaws-2016. The study reveals that fire-fighting/evacuation lifts and other fire protection systems are primarily present in the buildings. Nevertheless, due to inadequate maintenance or unsuitable elements, their safety performance is compromised.

Research findings- The analysis revealed that fire hoses and hydrants demonstrated the highest level of adequacy and suitability in terms of their number, locations, and maintenance across the buildings. Conversely, only 50% of the buildings had a sprinkler system that was sufficiently installed, indicating a need for improved coverage and maintenance, possibly due to cost considerations. The performance of other systems was as follows: fire driveways (83%), fire escape staircases (83%), fire detection and alarm (40%), corridors and passageways (67%), assembly areas (83%), hose reels and hydrants (100%), fire brigade access and facilities (67%), safety signs and notices (17%), portable fire extinguishers (50%), and fire audits (17%).

Based on these findings, it is recommended to prioritize increased efforts in inspecting and maintaining fire protection systems throughout the lifespan of the project to address the identified shortcomings. Additionally, the design of residential high-rise buildings should incorporate provisions for fire-fighting evacuation lifts and facilities catering to the needs of disabled individuals.

Keywords: High-rise, Fire protection, Maintenance, evacuation optimisation, fire protection system

1. INTRODUCTION

The emergence of high-rise buildings during the 19th Century introduced a new form of sophisticated urban living to address the growing demands for limited space in cities [2]. High-rise buildings have become the preferred solution for many municipal governments grappling with shrinking land availability and rising property prices worldwide [3]. With advancements in technology and scientific innovations, high-rise buildings have incorporated essential life support systems such as air circulation, lighting, elevators, and lifts, providing occupants with comparable comfort to low-rise buildings. According to the National Fire Protection Association [2], a high-rise building is defined as a structure exceeding 75 ft. (23 meters) in height, measured from the lowest level accessible by fire department vehicles to the floor of the highest occupiable story.

Fire protection encompasses fire prevention and suppression measures throughout the design and occupancy of a building. Each fire safety element typically incorporates three critical safety controls: physical control, management control, and human control in fire safety management.

The NFPA guide to fire safety [2] emphasizes major safety controls, highlighting the avoidance of risks when possible, assessment and evaluation of unavoidable risks, combating risks at their source, adapting control measures to technological progress, and replacing hazardous substances/articles with non-dangerous or less dangerous

alternatives. It further emphasizes the development of a comprehensive prevention policy that encompasses technology, work organization, and factors related to the working environment. Priority should be given to collective protective measures, and appropriate instruction should be provided to employees.

In developed countries, where comprehensive inventories of fire incidents and loss estimates are conducted, it has been established that approximately 350,000 fires occur annually in the U.K., resulting in 10,000 injuries and significant material losses. Workplace fires account for around 180,000 of these incidents. In England and Wales, the annual cost of fire has been estimated at £7.7 billion, with domestic fires averaging a cost of £25,000. According to research conducted by the Georgia Institute of Technology [4], the United States consistently experiences higher measures of fire loss compared to other industrialized nations, including loss of life, property damage, environmental degradation, time lost, and business disruptions.

In addition to the conventional fire protection challenges faced by various occupancies, high-rise buildings encounter unique and complex obstacles. These challenges include limited accessibility for fire equipment due to height, issues related to stair egress and smoke control, inconsistent fire safety management across different floors, alterations and changes from the building's original intended use, and the presence of intricate vertical utility services, particularly heating, ventilating, and air conditioning systems (HVAC).

While non-structural fire protection systems/methods, such as training and fire drills, are typically implemented during the operational phases of a project, most physical systems and methods are installed during the building design phase.

In context to the fire safety in high buildings in India, it has been noted that the residential and commercial buildings in the nation are subjected to various fire incidents and hazards because of lack of instruments, building layout and awareness. The violation of fire safety norms by various residential and commercial buildings in the nation has further contributed to the complexity of the situation. Fire safety- In Bengaluru, there are 900 high-rise buildings above 40mts in height, among which 132 buildings have been issued notices for improper fire safety measures and not conducting fire audits. One fire accident is witnessed every day in Bengaluru. 2847 building fire accidents occur between 2017-2022 in Table 1.

Table 1. Fire Accidents in Bengaluru from the year 2017-2022

Cause	Short circuit	Gas leak	Chemical	Oil leak	Cigarette	Total
2017	331	152	7	11	13	514
2018	407	170	4	3	19	603
2019	405	172	6	12	21	616
2020	337	146	10	9	11	513
2021	327	122	14	15	12	490
2022	82	23	0	0	6	111
Total	1889	785	41	50	82	2847

Source: Department of fire and emergency Services.

Based on the aforementioned points, the primary objective of this paper is to assess the extent of implementation of structural/physical fire protection systems and methods concerning the specific fire protection challenges present in residential high-rise buildings in Bengaluru. The ultimate goal is for the research findings to significantly enhance fire safety measures in residential high-rise buildings, thereby optimizing overall safety standards.

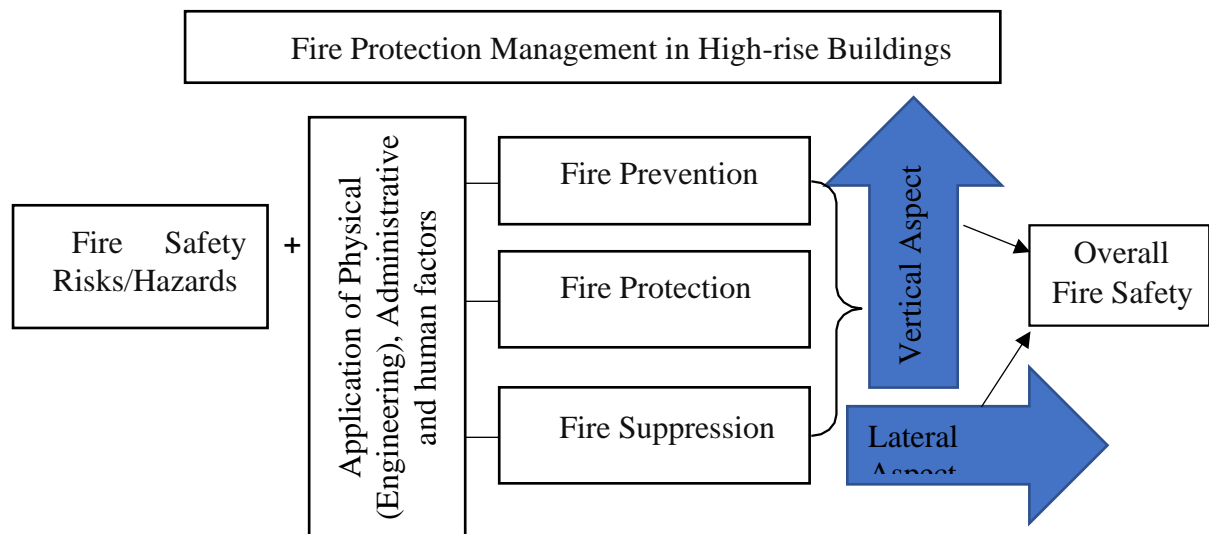


Figure 1. Systems Approach for Fire Safety Management, (modified from P. Rama Murthy [5] by author)

In practical terms, fire protection involves several steps, including the installation of fixed fire protection systems during building construction, as well as the subsequent installation and maintenance of specific fire protection equipment and installations. Over time, these fire protection systems can deteriorate in their effectiveness and functionality due to various factors such as decay, obsolescence, vandalism, negligence, interference, or changes made by users [6-7].

Individual testing is required for all fire safety installations. Additionally, interdependent fire safety installations should undergo collective testing to ensure proper interfacing and interlinking, among other factors. It is crucial to establish arrangements for regular inspections and maintenance of all fire protection systems, including fire detection and alarm systems, fire door control mechanisms, stair and lobby pressurization systems, evacuation and fire-fighting lifts, portable and fixed fire extinguishers, emergency lighting systems, and standby power systems [8].

1.1 Existing Legislations and initiatives

According to the National Building Code of India (NBC) [1] which was amended in 2019, high-rise buildings must comply with specific fire safety regulations to ensure the safety of occupants in case of a fire. Some of the essential requirements are:

E-1 GENERAL: High-rise buildings (15 m and above in height) shall receive special attention concerning fire and life safety, particularly concerning planning, design, execution, maintenance, and training so that the intended provisions of this Code are well implemented. These get further accentuated as the buildings go taller; some key aspects are as follows: a) Staging and evacuation requirements of occupants. b) Stack effect posing challenges towards pressurization and smoke exhaust. c) Zoning of the fire-fighting system to meet operating hydraulic pressure and flow requirements. d) Challenges experienced by fire personnel in reaching the place of fire and towards evacuation.

E-2 EGRESS AND EVACUATION STRATEGY: One fire-fighting shaft shall be planned for each residential building/tower in an educational building/ block and for each compartment of institutional, assembly, business, and mercantile occupancy types.

E-3 FIRE SAFETY REQUIREMENTS FOR LIFTS: The provisions as given in 7.1 to 7.2.4 under fire safety requirements of lifts in high-rise buildings in Part 8

E-4 HORIZONTAL EXITS/REFUGE AREA: A horizontal exit shall be through a fire door of 120 min rating in a fire-resistant wall. Horizontal exits require separation from the refuge area or adjoining compartment through 120 min fire barrier. The adjoining compartment of the horizontal exit should allow unlocked and ease of egress and exits for the occupants using defend in place strategy. High-rise apartment buildings with apartments having a balcony need not be provided with a refuge area; however, apartment buildings without a balcony shall provide a refuge area as given above. Refuge areas for apartment buildings above 60 m while having balconies shall be provided at 60 m and at every 30 m. The refuge area shall be an area equivalent to 0.3 m² per person for accommodating occupants of two

consecutive floors, where occupant load shall be derived on the basis of 12.5 m² of gross floor area and additionally 0.9 m² for accommodating wheelchair requirement or shall be 15 m², whichever is higher

E-5 ELECTRICAL SERVICES: The specific requirements for electrical installations in multi-storeyed buildings given in Part 8, 'Building Services, Section 2 Electrical and Allied Installations' of the Code and Section 7 of the National Electrical Code 2011 shall be followed.

E-7 FIRE AND LIFE SAFETY AUDIT: a) Fire and life safety audit shall be carried out for all buildings having a height of more than 15 m. b) Such audits shall preferably be conducted by a third-party auditor having requisite experience in fire and life safety inspections. c) Frequency of such audits shall be once in two years.

E-8 HELIPAD For high-rise buildings above 200 m in height, provision for a helipad is recommended for specific requirements like the landing of fire equipment and support facilities or other emergencies.

2. MATERIAL AND METHODS

2.1 Description of Case studies

The case studies chosen are the buildings within the BMRDA (Bangalore Metropolitan Regional Development Authority). The height of the buildings chosen is above 15mt and less than 75mt. The complete residential high-rise buildings are selected as a sample. The legally sanctioned high-rise is studied as a sample. The situations of the buildings are as in Table 1.

Table 2. The buildings involved in the study

Sl. No	Name of the building	Year of Construction	No of Floors	Location
1.	Building-1	2006	14	Kanakapura road
2.	Building-2	2010	14	JP NAGAR
3.	Building-3	2010	23	Sarjapur Road
4.	Building-4	2012	14	Old Airport Road
5.	Building-5	2018	11	Devanahalli
6.	Building-6	2019	14	Devanahalli

2.2 Sampling Design

A cross-sectional survey was conducted on six residential high-rise buildings within the Bangalore BMRDA limits, utilizing a mixed methods approach that included both quantitative and qualitative techniques. The sampling process involved generating a representative sample using random tables, where all identified residential high-rise buildings in the metropolis were listed. Through the use of random tables, six buildings were selected for the study.

Individuals for interviews were selected using convenience and snowball sampling techniques [9]. Key participants included relevant individuals from the Karnataka State Fire and Emergency Services Department (Building Section) and building managers from all the surveyed buildings. The aim was to gather insights and information from various perspectives to ensure a comprehensive understanding of the subject matter, while maintaining the integrity of the original statement.

2.3 Methods and Techniques

The data collection process involved conducting physical observations and inspections using a Fire Safety Risk Assessment checklist [2] specifically designed for this study. Additionally, literature and documents such as inspection/maintenance reports, improvement orders, as well as interviews with building managers, occupants, and professionals in the construction sector were utilized. Each fire protection system was thoroughly examined against national laws and standards to assess its adequacy and appropriateness. In cases where local standards required improvement or were insufficient, international standards and practices were consulted.

Given the diverse range of fire protection systems and methods available, a multi-attribute Evaluation Model/Approach [10] was employed. This approach facilitated the calculation of the overall performance of the systems in different buildings. An ordinal scale was used, with hierarchical levels represented by A, B, and C, to evaluate the performance

of each system or method in individual buildings. Level A denoted a sufficient and suitable system, level B indicated an insufficient or unsuitable system, while level C signified the absence of a particular system or method.

3. ANALYSIS AND RESULTS

The analysis relies on the findings from observations or inspections of the different fire protection systems examined in the study, as outlined in table 2. As mentioned earlier, A denotes the adequacy and appropriateness of the system, while B signifies its inadequacy and unsuitability. C indicates the absence or lack of the system.

Table 3. Status of fire protection systems status in buildings

Sl. no	Fire Protection System																	
Building Names																		
	Fire driveway	Fire escae staircase	Corridors and passageways Access for fire fighting		Assemblv area	Refuge area	Helipads	Fire Alarms	Smoke Detectors	Sprinklers	Portable Fire Extinguishers	Fire hoses	Safety Notices & Singages	Egress and evacuation Strategy	Electrical Services	Fire Audits		
1	Building- 1	B	B	B	A	A	B	NA	A	B	B	B	A	B	C	B	B	
2	Building- 2	A	A	B	B	C	B	NA	A	A	B	B	A	B	C	A	B	
3	Building- 3	A	A	A	B	A	B	A	A	B	B	B	A	B	C	A	B	
4	Building- 4	A	A	A	A	A	A	NA	A	A	B	A	A	B	B	A	B	
5	Building- 5	A	A	A	A	A	A	NA	A	B	B	A	A	B	B	A	B	
6	Building- 6	A	A	A	A	A	A	NA	A	A	A	A	A	A	B	A	A	
	No of Buildings	A	5	5	4	4	5	3	0	6	3	1	3	6	1	0	5	1
		B	1	1	2	2	0	3	1	0	3	5	3	0	5	3	1	5
		C	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	
		NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4. Summary of the status of fire protection systems

Sl. No	System	Sufficient/ suitable	Percentage	Insufficient/ Not suitable	Percentage	Missing/ Not available	Percenta ge
1	Fire driveway	5	83	1	17	0	0
2	Fire escae staircase	5	83	1	10	0	0
3	Corridors and passageways	4	67	2	33	0	0
4	Access for fire fighting	4	67	2	33	0	0
5	Assembly area	5	83	0	0	1	17
6	Refuge area	3	50	3	50	0	0
7	Helipads	0	0	1	100	0	0
8	Fire Alarms	6	100	0	0	0	0
9	Smoke Detectors	3	50	3	50	0	0
10	Sprinklers	1	17	5	83	0	0
11	Portable Fire Extinguishers	3	50	3	50	0	0
12	Fire hoses	6	100	0	0	0	0

13	Safety Notices & Signages	1	17	5	83	0	0
14	Egress and evacuation Strategy	0	0	3	50	3	50
15	Electrical Services	5	83	1	17	0	0
16	Fire Audits	1	17	5	83	0	0

4. RESULTS, FINDINGS, AND DISCUSSIONS

4.1 Fire driveways

Visual Observations showed that the fire driveways were provided in all six buildings, and five buildings were free from any obstacle, but it was noticed that one of the buildings was blocked by parking as represented in figure A. The fire tender movement should be free of obstructions and be motorable. The compulsory open spaces around the building shall not be used for parking [1].

4.2 Fire escape Staircase

The fire escape Staircase was sufficiently provided in all the buildings; in one of the buildings, it was not a separate Fire exit, and the standard staircase was used as a fire stair and was not provided with closed doors, and the signage needed to be included as represented in B. Sprinkler heads, poor housekeeping (leading to dusty conditions, which could trigger alarm system activation), inadequate reserve water, and poor implementation of the maintenance program after inspection were crucial factors that rendered the system insufficient.

4.3 Corridors and passageways

The corridors and passageways provided are adequately lit and barrier-free, with proper width according to NBC-2016 [1] and proper signages of the fire exit being indicated [Fig: C]. The buildings under the insufficient category need better lighting and proper signage in the corridors and passageways, which lead to the fire exits like the doorways, fire escape staircase, lobby, ramps, and corridors. The observations are that 67% of the buildings have access to the blocks, and even the risers are accessible. 33% of the buildings need proper access due to the blocking of balconies [Fig: C].

4.4 Refuge area

The observation is that the buildings under the excellent category have balconies open as a refuge area which has been observed in 50% of the buildings [Fig E]. The buildings under the insufficient category have blocked the balconies with grills and glazing.

4.5 Smoke detectors

For 50% of the buildings, the observation is that the buildings under the sufficient category have smoke detectors in a plane and are also maintained well [Fig G]. However, the buildings under the insufficient category need to be maintained, and in a few buildings, the detectors are blocked.

4.6 Sprinklers

The buildings only have sprinklers in the basement, whereas the fire escape corridors have a sprinkler system [11]. Portable extinguishers are part of fire safety equipment in most buildings which has been recorded in 50% of the buildings, but the type of extinguisher placed is only the dry carbon extinguisher [Fig I]. The numbers and the types were different from those [1].

4.7 Signage and safety notices

The buildings do not have proper signage and safety notices that have been observed in 83% of the buildings, which are supposed to be placed at the entrances and the staircases [Fig J]. The floor plans showing the escape route and fire exits were also missing.

4.8 Egress and Evacuation Strategy

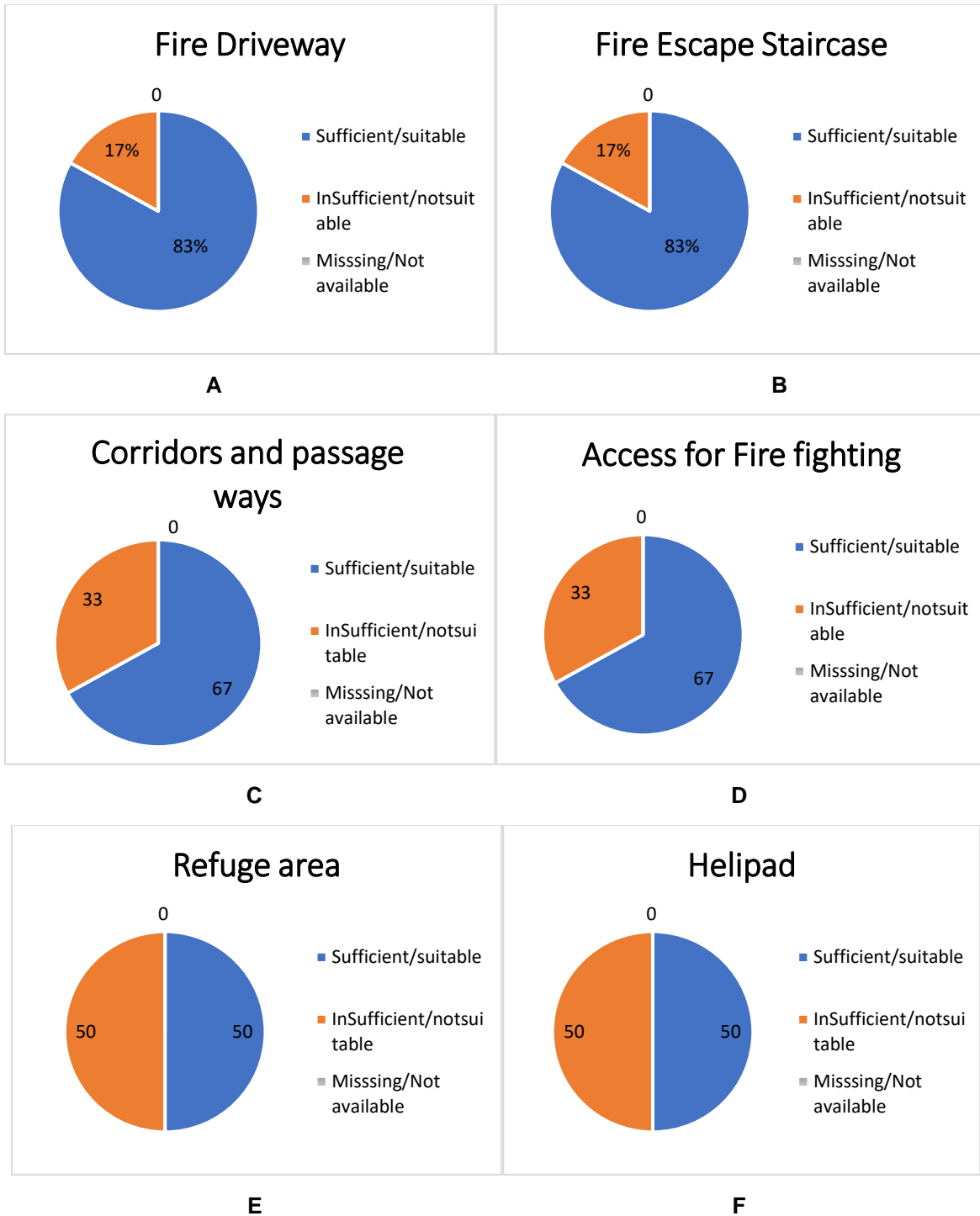
Only 50% of the buildings have the strategies planned, and most of the buildings still need the evacuation strategies planned [Fig K].

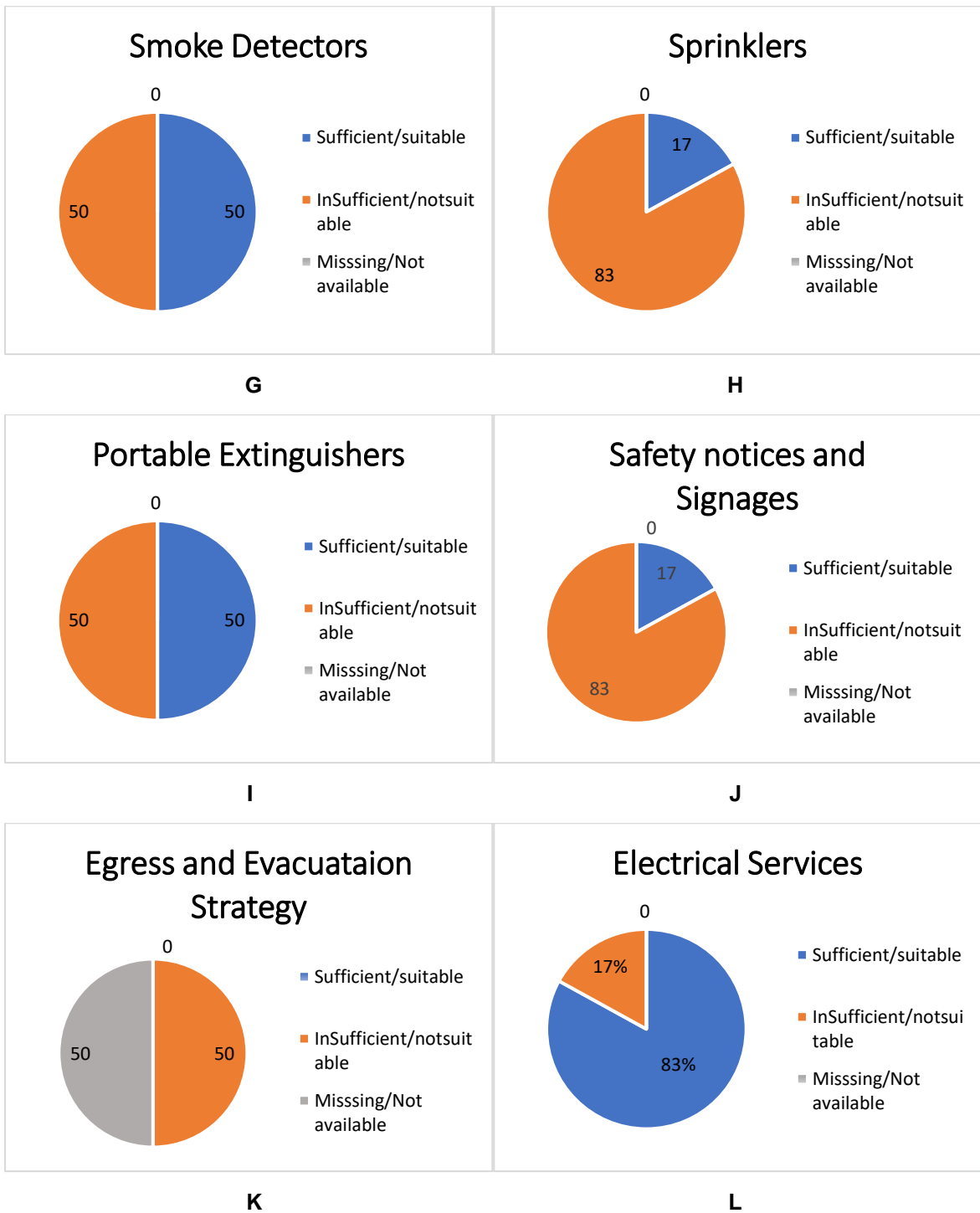
4.9 Electrical Services

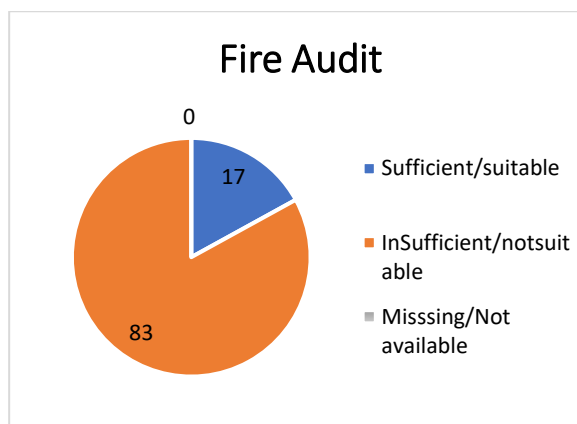
Low-percent buildings need well-maintained electrical ducts; the ducts are exposed without doors, wherein 83% of the buildings have been observed to have sufficient electrical services [Fig L].

4.10 Fire Audit

The fire audits, which must be conducted annually, according to NBC-2016 [1], should be done more regularly in most buildings as majority of the buildings that is 83%, have been observed to have insufficient fire audit [Fig M].







M

Figure 2 [Figure A: Distribution of buildings with and without adequate and/or suitable Fire Driveway, Figure B: Distribution of buildings with and without adequate and/or suitable Fire Escape Staircase, Figure C: Distribution of buildings with and without adequate and/or suitable Corridors and passageways, Figure D: Distribution of buildings with and without adequate and/or suitable Access for Firefighting, Figure E: Distribution of buildings with and without adequate and/or suitable Refuge area, Figure F: Distribution of buildings with and without adequate and/or suitable Helipad, Figure G: Distribution of buildings with and without adequate and/or suitable Smoke detectors, Figure H: Distribution of buildings with and without adequate and/or suitable Sprinklers, Figure I: Distribution of buildings with and without adequate and/or suitable Portable Extinguishers, Figure J: Distribution of buildings with and without adequate and/or suitable Safety Notices and Signage, Figure K: Distribution of buildings with and without adequate and/or suitable Egress Evacuation Strategy, Figure L: Distribution of buildings with and without adequate and/or suitable Electrical Services, Figure M: Distribution of buildings with and without adequate and/or suitable Fire Audit.]

5. CONCLUSION AND RECOMMENDATIONS

In conclusion, it is evident that while many residential high-rise buildings are equipped with fire protection systems such as fire detection and alarm systems, as well as portable and fixed fire extinguishers, there are significant shortcomings in their maintenance. One major obstacle to proper maintenance is the lack of effective implementation of recommendations following inspections. Additionally, a survey revealed that none of the buildings (100%) have crucial fire protection systems like fire-fighting and evacuation lifts, or facilities for disabled individuals. To achieve optimal fire safety in residential high-rise buildings, the following recommendations should be followed:

- a) Occupiers should consider maintenance of fire protection systems and methods as part of their management responsibility, rather than viewing it as an extra expense. It should be seen as a necessary investment.
- b) Thorough inspections, reporting, feedback, and prompt remedial actions should be carried out diligently to safeguard property, lives, and the environment.
- c) Future construction projects for residential high-rise buildings should include provisions for fire-fighting and evacuation lifts. Additionally, facilities for disabled individuals should be incorporated into the design stage.

By implementing these recommendations, we can ensure enhanced fire safety measures in residential high-rise buildings without altering the intended meaning.

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