

IS-Aligned Strategic Evaluation of Fire Protection Systems for Improving Fire Safety in Mixed-Occupancy High-Rise Buildings

Pravin Tathod^{1*}, Vishesh Singh Raghav², Ashish Deshmukh³, Rudraksh Yadav⁴, Karan Gound⁵

Abstract

This paper presents a substantially reworked Indian-context evaluation of fire protection systems in a 14-building high-rise sample from Indore. The study reuses the original field dataset but replaces the earlier code mix with an explicitly IS-aligned and NBC-oriented analytical framework. Physical observation, document review and interview inputs were screened against requirements related to means of egress, compartmentation, fire detection and alarm, hydrants and hose reels, extinguishers, emergency lighting, smoke control, brigade access, sprinkler protection and inclusive evacuation. A three-level rating scale was retained (A = adequate/suitable, B = deficient/unsuitable, C = absent/not available), and a derived Composite Fire Protection Compliance Index was introduced to improve interpretability. The analysis shows that portable fire extinguishers achieved the best performance, while emergency lighting, compartmentation, internal hydrant infrastructure and fire brigade access were moderately stronger than other systems. In contrast, automatic sprinklers were never fully adequate within the sample, safety signage remained weak, and assembly point planning was often missing. Facilities for disabled evacuation and firefighting/evacuation lifts were absent in all evaluated buildings. The findings indicate that the dominant gap is not only non-provision, but also weak maintainability, incomplete operability and inadequate evacuation support. The paper concludes with a prioritized intervention matrix for design-stage correction, retrofit planning, inspection discipline and operations-focused fire safety improvement.

Keywords: Fire protection systems, mixed-occupancy high-rise buildings, Indian Standards, NBC 2016, fire safety assessment, evacuation readiness, maintenance compliance

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INTRODUCTION

High-rise buildings concentrate the population, assets, vertical services, and diverse occupancy functions within a comparatively limited footprint. As the height and functional complexity of buildings increase, fire safety performance becomes increasingly dependent on the coordinated operation of passive fire protection, active systems, emergency power, wayfinding, evacuation planning, and fire brigade accessibility [1–3].

The challenge becomes more pronounced in mixed-occupancy environments, where retail, residential, hospitality, healthcare, or office functions may coexist in a single vertical envelope.

Such buildings rarely fail because of a single component alone; instead, failure typically emerges from weak integration between detection, containment, suppression, egress, and maintenance systems. Indian code provisions recognize this interdependence and require mixed occupancies to be examined through the most restrictive fire protection lens while applying life safety provisions to the relevant individual occupancy [1, 2].

The uploaded draft manuscript already contained a useful 14-building field dataset, but it also mixed jurisdictions, included non-Indian references, and presented inconsistent narrative interpretation. Therefore, the present study retains the original case data while re-authoring the manuscript around Indian Standards, NBC 2016, a more coherent literature structure, corrected analytics, and publication-grade tables and Figures [1–8].

The study has four objectives: first, to examine the adequacy of major fire protection and life safety systems in the sampled buildings; second, to identify the dominant patterns of deficiency and absence; third, to derive a composite compliance index that improves comparison across systems and buildings; and fourth, to recommend practical IS-aligned measures for improving fire safety in mixed-occupancy high-rise buildings.

AREA OF STUDY

The study boundary is Indore, a rapidly expanding urban center in Madhya Pradesh, where vertical development has increased across residential and mixed-use corridors. The sample retained from the source manuscript consisted of 14 anonymized buildings ranging from 10 to 25 floors. Occupancy categories represented in the dataset include mixed-use, residential, hotel, hospital, and commercial buildings.

Although the accompanying handbook is framed around residential buildings, it remains useful as an interpretive Indian reference because it synthesizes NBC 2016 Part 4 provisions, emphasizes mixed-occupancy treatment, and highlights constructional, life safety, and fire protection interfaces relevant to high-rise evaluation [2]. Therefore, the present study uses the handbook as a code-aligned interpretive aid rather than as a substitute for primary standards Table 1.

Table 1. Profile of evaluated buildings.

Building ID	Floors	Year	Occupancy type
Occupancy-1	25	2023	Mixed Use
Occupancy-2	17	2017	Residential
Occupancy-3	16	1999	Hotel
Occupancy-4	16	2013	Residential
Occupancy-5	16	2015	Residential
Occupancy-6	16	2016	Residential
Occupancy-7	15	2018	Residential
Occupancy-8	15	2012	Residential
Occupancy-9	15	2004	Hospital
Occupancy-10	24	2022	Residential
Occupancy-11	15	2016	Residential
Occupancy-12	10	2010	Commercial
Occupancy-13	15	2011	Mixed Use
Occupancy-14	15	2018	Residential

LITERATURE SURVEY AND RESEARCH GAP

Indian fire safety literature relevant to tall buildings can be grouped into three layers: (i) mandatory and quasi-mandatory code instruments that define baseline provision requirements; (ii) handbooks and guidance documents that translate those requirements into building-level design and operations language; and (iii) empirical or conceptual studies that evaluate post-occupancy performance, maintenance, and evacuation adequacy. Table 2 synthesizes the most relevant sources used to frame the present study.

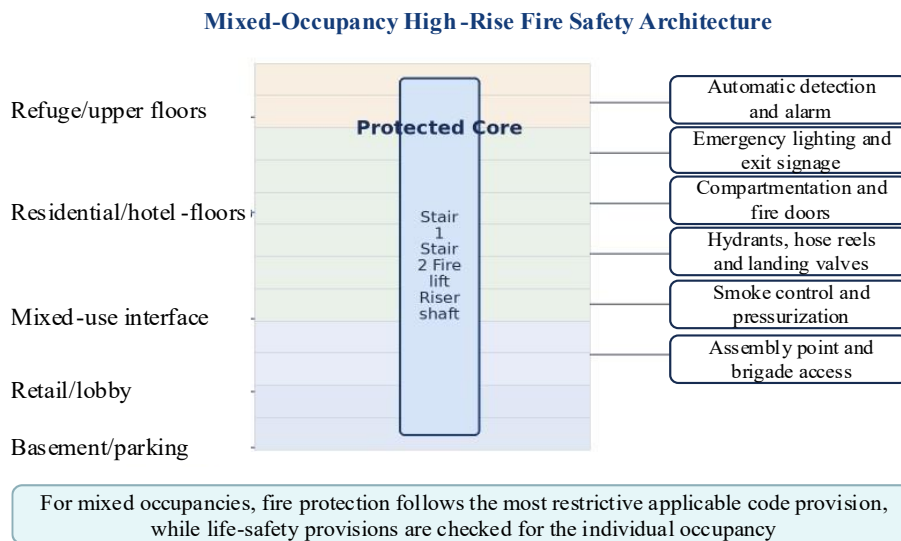


Figure 1. Indicative mixed-occupancy high-rise fire safety architecture.

Table 2. Literature and standards synthesis.

Source	Primary focus	Key insight	Gap relevant to this study
NBC 2016 Part 4 [1]	National fire and life safety code framework	Defines occupancy-wise requirements for fire prevention, life safety and fire protection in buildings.	Prescriptive basis exists, but building-level adequacy studies remain limited.
Residential Fire Safety Handbook [2]	Interpretive Indian handbook	Explains egress, compartmentation, emergency lighting, alarms, smoke control and mixed-occupancy treatment.	Useful for application, but not a substitute for empirical evaluation.
SP 73:2023 [3]	Regulatory harmonization	Reinforces alignment of development regulations with NBC provisions.	Supports regulatory consistency rather than field performance assessment.
IS 1641/1642/1644/1646 [4–7]	Construction, exits and electrical fire safety	Provide technical basis for grading, construction detailing, exit design and electrical safety.	Need to be translated into practical screening criteria for audits.
IS 15105/IS 2190/IS 13039 [8–14]	Active system installation and maintenance	Address extinguishers, sprinklers and hydrant systems as maintainable infrastructure.	Provision does not guarantee continued reliability in occupied buildings.
Furness and Muckett [15]	Fire safety management	Emphasize integration of technical systems and management control.	Management insights require system-specific field indicators.
Rasbash <i>et al.</i> [16]	Fire safety evaluation	Support structured performance-oriented evaluation approaches.	Need localization to Indian code conditions and available data.
Yatim and Harris [17]	High-rise escape route evaluation	Show that escape adequacy is shaped by obstruction, signage and operational readiness.	Escape routes must be assessed alongside other interacting systems.

The synthesis is intentionally limited to Indian code-relevant sources and fire safety evaluation literature used in the paper.

Therefore, the key research gap is not the absence of technical prescriptions but the limited availability of structured post-occupancy studies that translate Indian fire and life safety requirements into a comparative adequacy assessment for mixed-occupancy high-rise buildings. A second gap lies in the under-reporting of systems that are present but functionally weak because of poor maintenance, poor siting, or incomplete operational readiness. The third gap is the lack of a concise comparative indicator that can help rank systems and buildings for corrective action. This study addresses these gaps by combining the retained field ratings with an IS-aligned screening framework and a derived compliance index [17–20].

Recent high-rise fire safety research has moved toward phased evacuation optimization, behavior-based evacuation reviews, simulation-aided egress design, predictive fire-risk pre-warning, personnel literacy, disability-inclusive evacuation, façade-fire vulnerability analysis, and sprinkler reliability assessment [21–32]. These contributions sharpen the understanding of system interactions, but most remain simulation-centric, sector-specific, or jurisdiction-specific. Therefore, a clear gap persists in converting such insights into an Indian Standards-based, mixed-occupancy audit framework that is directly usable for field appraisal, regulatory screening, and retrofit prioritization [21–33, 34–43].

PROBLEM IDENTIFICATION AND PROBLEM FORMULATION

The source dataset indicates that fire safety shortfalls are unevenly distributed across the system architecture of high-rise buildings. Some elements, such as portable extinguishers and internal hydrant infrastructure, are commonly observed. Others, such as sprinklers, safety signage, and assembly point planning, showed low adequacy or major functional gaps. The most severe deficits were related to inclusive evacuation and firefighting support infrastructure, including facilities for disabled evacuation and firefighting/evacuation lifts, both of which were fully absent in the retained sample [44–46].

Accordingly, the problem addressed in this study is formulated as follows: how can the provision, adequacy, and operational quality of fire protection systems in mixed-occupancy high-rise buildings be evaluated in a manner that is aligned with Indian Standards and produces a clear basis for prioritizing design corrections, retrofits, and maintenance actions?

The evaluation was organized around three research questions: (i) Which systems are adequately provided in the sampled buildings? (ii) Which systems remain deficient or absent despite their fire and life safety importance? (iii) What comparative pattern emerges when building-level observations are converted into a composite compliance index?

MATERIALS AND METHODOLOGY

This study adopts a cross-sectional mixed-method approach based on the 14-building dataset retained from the uploaded draft. Data collection in the source study combined physical observation, document review, and interviews with building-level stakeholders. For the present rewritten manuscript, those records were reorganized into a code-aligned evaluation framework rooted in the NBC 2016 Part 4, the residential fire safety handbook, and supporting BIS standards [1–10].

The original three-point rating scale was preserved because it is well suited for field screening: A = adequate/suitable, B = deficient/unsuitable, and C = absent/not available. Two derived metrics were added to improve the comparative interpretation. The first is the system adequacy percentage, which indicates the proportion of buildings rated A for a given system. The second is the Composite Fire Protection Compliance Index (CCI), which converts A, B, and C to numerical scores of 2, 1, and 0, respectively, and normalizes the result to a percentage scale Table 3.

$$\text{System Adequacy (\%)} = (A / n) \times 100$$

$$\text{System CCI (\%)} = ((2A + B) / (2n)) \times 100$$

$$\text{Building CCI (\%)} = (\sum \text{score}_i / (2m)) \times 100, \text{ where } m = 13 \text{ evaluated systems}$$

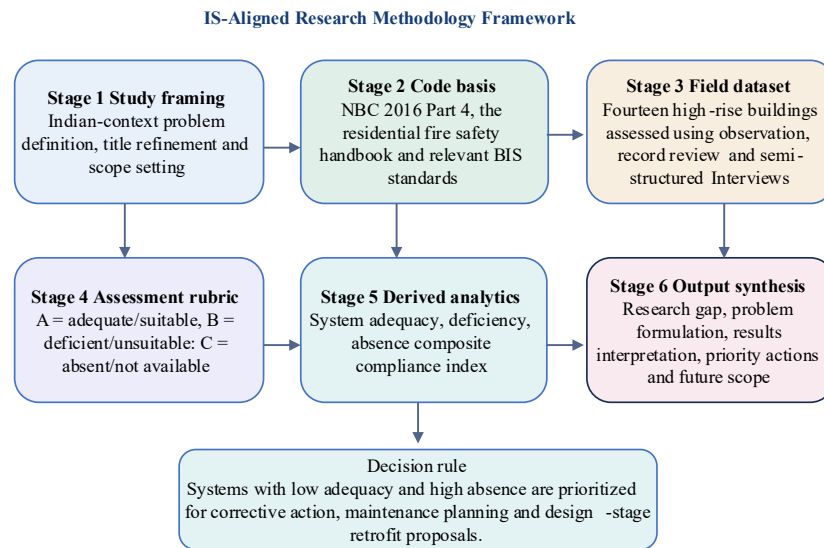


Figure 2. IS-aligned methodology adopted.

Table 3. IS-aligned assessment framework used for screening.

System element	Assessment intent	Reference basis
Automatic sprinklers	Coverage, operability, water supply, zoning and maintenance status	NBC 2016 Part 4; IS 15105 [1, 9]
Fire detection and alarm	Detector provision, panel logic, warning audibility, call points and maintainability	NBC 2016 Part 4; IS 2189 [1, 11]
Escape routes	Availability, obstruction-free condition, door performance and travel support	IS 1644; handbook [2, 6]
Emergency lighting	Independent source, continuity, visibility and emergency readiness	Handbook; NBC 2016 Part 4 [1, 2]
Smoke control	Stair/lobby pressurization, smoke movement control and functional readiness	Handbook; NBC 2016 Part 4 [1, 2]
Compartmentation	Barrier integrity, fire doors, shaft protection and fire stopping	IS 1642; handbook [2, 5]
Riser mains / hose reels / hydrants	Internal water-based firefighting reach, access and maintainability	NBC 2016 Part 4; IS 13039 / IS 3844 [1, 10, 14]
Facilities for disabled evacuation	Inclusive evacuation provision, refuge support and assisted movement readiness	Handbook; life-safety principles [1, 2]
Fire brigade access	Approach roads, inlets, access points and firefighting usability	NBC 2016 Part 4; handbook [1, 2]
Firefighting and evacuation lifts	Dedicated lift support for fire service operations and emergency movement	NBC 2016 Part 4 [1]
Safety signs and notices	Location, clarity, visibility and directional usefulness	Handbook; exit sign provisions [2]
Portable extinguishers	Suitability by hazard, siting, servicing and accessibility	IS 2190; IS 15683 [8, 13]
Fire assembly points	Availability, usability and evacuation accounting support	Fire safety management practice [2, 15]

The framework translates code provisions into a field-appraisal structure suitable for comparative system screening.

RESULTS AND ANALYSIS

The rewritten analysis was derived directly from the row-wise A/B/C ratings in the uploaded field Table 4. Because the earlier manuscript contained several narrative inconsistencies, all percentages reported below were recomputed from the retained building-level observations before being converted into charts and compliance indices.

Portable fire extinguishers recorded the strongest overall performance, with 78.6 percent of buildings rated adequate and a system CCI of 89.3 percent. This suggests that first-aid firefighting appliances are comparatively well understood, widely deployed, and easier to maintain than larger integrated systems. Internal water-based firefighting infrastructure—riser mains, hose reels, and brigade access support—also showed moderate strength, whereas compartmentation and emergency lighting performed better than many other systems.

The second cluster of systems exhibited only moderate readiness. Escape routes and smoke control each reached 50.0 percent adequacy, indicating that approximately half of the sample still carries evacuation or smoke management weaknesses. Fire detection and alarm systems were present in every building but achieved only 21.4 percent adequacy, which implies that the dominant problem lies in performance quality, maintenance discipline, nuisance alarms, zoning, or interface integrity rather than outright non-provision.

Table 4. System-wise adequacy, deficiency, absence and compliance index.

System	A	B	C	Adeq. %	Defic. %	Absent %	CCI %
Sprinkler	0	12	2	0.0	85.7	14.3	42.9
Fire Detection & Alarm	3	11	0	21.4	78.6	0.0	60.7
Escape Route	7	6	1	50.0	42.9	7.1	71.4
Emergency Lighting	9	3	2	64.3	21.4	14.3	75.0
Smoke Control	7	6	1	50.0	42.9	7.1	71.4
Compartmentation	9	4	1	64.3	28.6	7.1	78.6
Riser/Hose Reels/Hydrants	9	5	0	64.3	35.7	0.0	82.1
Facilities for Disabled	0	0	14	0.0	0.0	100.0	0.0
Fire Brigade Access	9	5	0	64.3	35.7	0.0	82.1
Firefighting & Evacuation Lifts	0	0	14	0.0	0.0	100.0	0.0
Safety Signs & Notices	1	13	0	7.1	92.9	0.0	53.6
Portable Fire Extinguishers	11	3	0	78.6	21.4	0.0	89.3
Fire Assembly Points	3	3	8	21.4	21.4	57.1	32.1

A = adequate/suitable, B = deficient/unsuitable, and C = absent/not available.

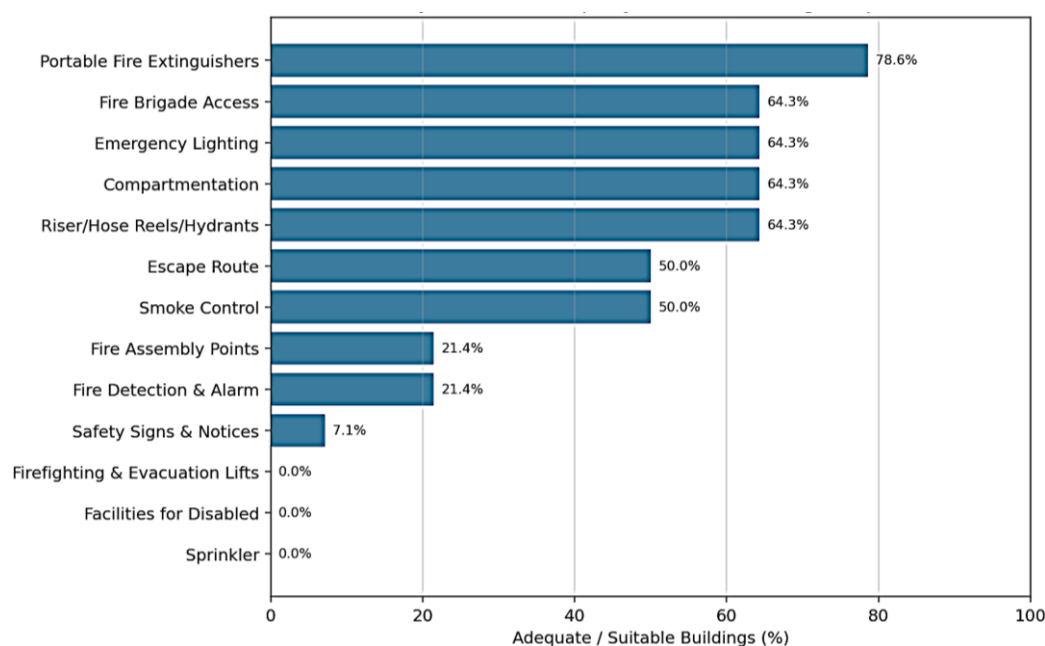


Figure 3. System-wise adequacy in the 14-building sample.

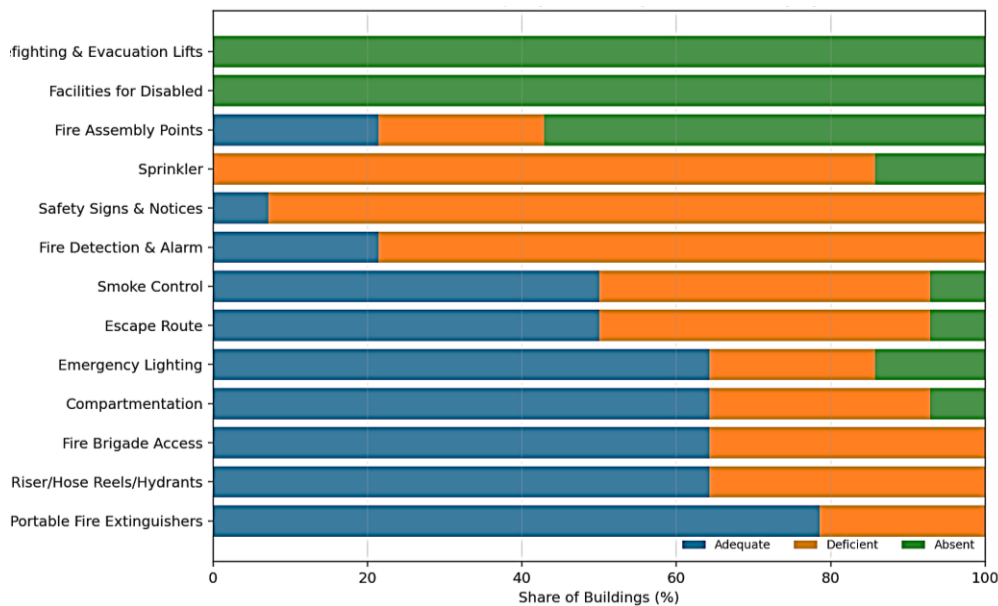


Figure 4. Distribution of adequacy, deficiency and absence by system.

Table 5. Priority interpretation of system-level findings.

Priority band	Systems	Observed issue	Preferred action direction
Critical design-gap priority	Facilities for disabled evacuation; firefighting/evacuation lifts	Full absence across the sample	Introduce at design stage in new projects and assess retrofit feasibility in existing tall buildings.
Critical retrofit priority	Automatic sprinklers; safety signs and notices	Near-zero adequacy with major operational consequences	Upgrade coverage, zoning, signage logic and maintenance protocols; verify water supply and interface readiness.
High operational priority	Fire detection and alarm; fire assembly points	Low adequacy or high absence despite evacuation importance	Standardize alarm maintenance, reduce nuisance conditions and formalize assembly planning.
Moderate system-performance priority	Escape routes; smoke control	Present but only moderately reliable	Improve obstruction control, fire door integrity, pressurization testing and evacuation usability.
Sustain and monitor	Emergency lighting; compartmentation; hydrants; brigade access; extinguishers	Relatively better performance but still not uniformly robust	Preserve serviceability through inspection, testing, documentation and corrective feedback closure.

Priority bands are derived from the combination of adequacy, deficiency, absence and system criticality.

The weakest systems are the most consequential for the resilience of high-rise buildings. No building in the sample achieved an adequate sprinkler rating; two buildings lacked sprinklers altogether, and the remainder were deficient. Safety signs and notices were adequate in only 7.1 percent of the buildings. Fire assembly points were often missing, and inclusive evacuation infrastructure was absent in all buildings; facilities for disabled evacuation and firefighting/evacuation lifts were both recorded as 100 percent absent. These results clearly differentiate maintainable shortfalls from the design-stage omissions Table 5.

To examine the variation across buildings rather than systems alone, a building-level CCI was calculated using the same A/B/C conversion logic. The resulting distributions are shown in Figure 5. Occupancy-1, Occupancy-7 and Occupancy-14 achieved the highest scores (73.1 percent each), whereas Occupancy-6 recorded the lowest score (19.2 percent). Occupancy-10 and Occupancy-4 also remained comparatively weak in this regard. The spread between the strongest and weakest buildings confirms that overall fire safety readiness is highly uneven, even within the same urban context.

The building-level pattern also shows that single-system observations are insufficient for decision-making. A building may appear acceptable because it contains extinguishers and hydrants, yet remains strategically weak if it lacks inclusive evacuation support, reliable signage, working detection logic, or sprinkler adequacy. Therefore, the composite index acts as a planning aid rather than a substitute for a detailed code compliance review.

Exploratory Secondary Pattern Analysis

Figure 6 summarizes the non-adequacy burden (deficient plus absent shares) across the evaluated systems. The chart clarifies intervention urgency more directly than the adequacy values alone. Systems linked to inclusive evacuation support and firefighting lift provision remain the most severe gaps, whereas sprinklers, signage, and alarm systems continue to show a substantial burden of corrective action.

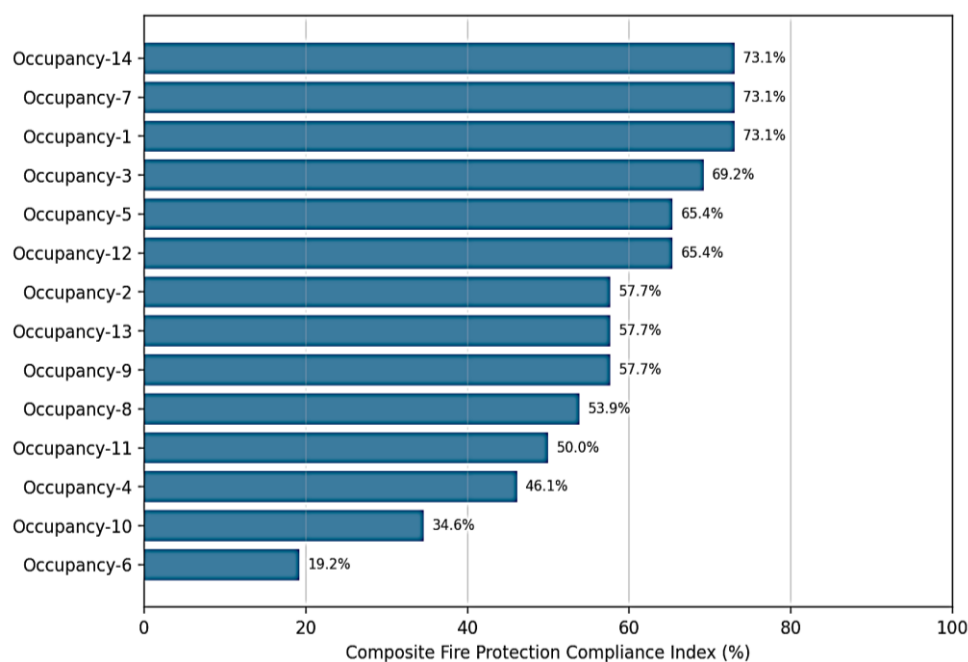


Figure 5. Building-wise Composite Fire Protection Compliance Index.

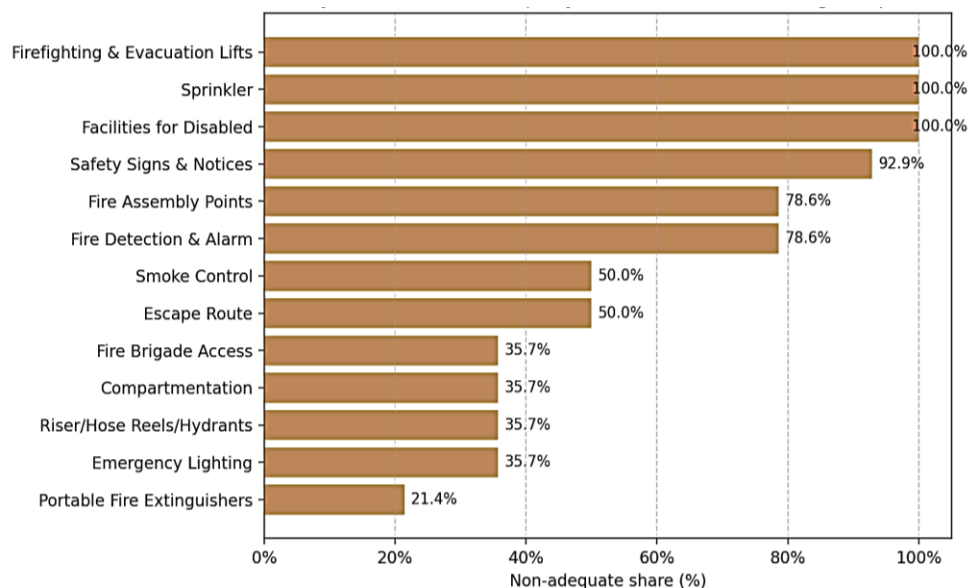


Figure 6. System-wise non-adequacy burden in the 14-building sample.

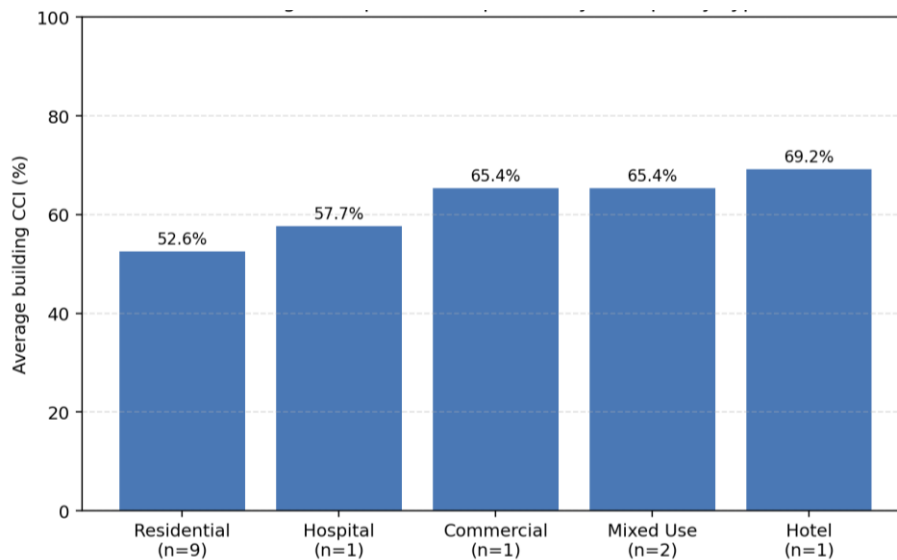


Figure 7. Average building-wise Composite Compliance Index by occupancy type.

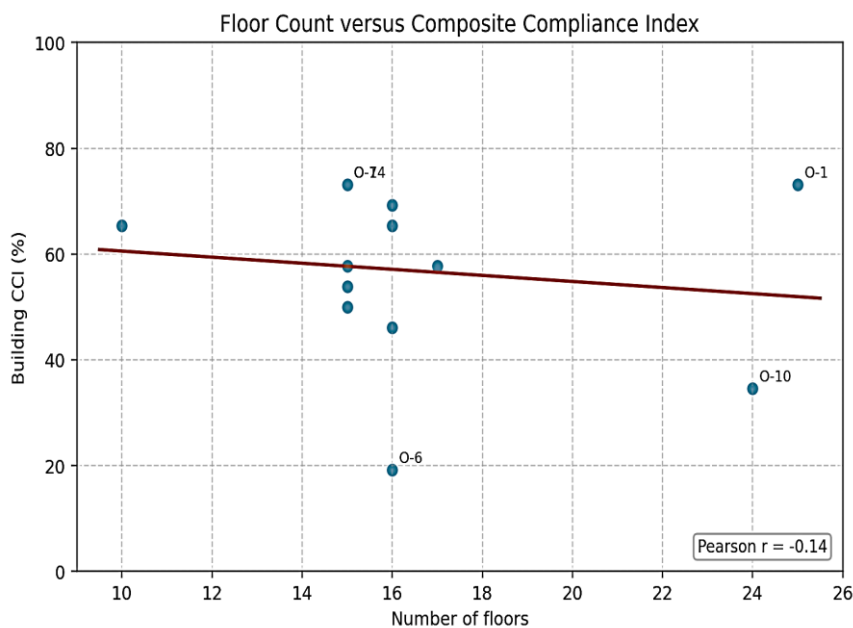


Figure 8. Floor count versus building-wise Composite Compliance Index.

An exploratory occupancy-wise comparison is presented in Figure 7. Because several occupancy groups in the inherited dataset contained only one or two buildings, the chart should be interpreted cautiously. This suggests that residential buildings exhibit the widest spread and the lowest average composite compliance, whereas the sampled mixed-use, hotel, and commercial cases perform somewhat better on average. This reinforces the need to examine management quality and system integration within each occupancy rather than assuming uniform performance based on the label alone.

Figure 8 compares the floor count with the building-level compliance index. The relationship was weak and slightly negative in this sample, indicating that greater height did not automatically correspond to stronger fire safety readiness. In other words, code era, complexity, maintenance quality, and operational discipline appear to matter more than floor count alone. The results also caution against assuming that recently constructed or taller buildings are inherently safer without verifying continued system operability.

DISCUSSION

Three broad insights emerged from this analysis. First, maintenance and operability are as important as the initial provision. Systems such as alarms, smoke control, and exit components may exist physically, yet still fail to support safe evacuation if detectors are poorly maintained, fire doors are compromised, or pressurization is not verified. Second, systems that are difficult or expensive to retrofit—sprinklers, firefighting lifts, and inclusive evacuation infrastructure—are the ones most likely to remain chronically weak. This highlights the need for stronger design-stage enforcement in tall buildings.

Third, evacuation reliability depends on the chain linking detection, warning, lighting, signage, protected routes, assembly, and fire brigade intervention. Weakness in any one of these segments can reduce the practical value of the others. For example, an adequately compartmented building can still present life-safety risks if the signs are unclear, assembly areas are missing, or the fire brigade lacks protected operational support.

The findings also support the handbook's mixed-occupancy principle: where multiple occupancies coexist, fire protection should be governed by the most restrictive applicable requirement, while life-safety checks must remain sensitive to the user characteristics of the actual occupancy served [2]. This is particularly important in buildings where commercial podiums, residential towers, and hotel floors are vertically combined.

Nevertheless, the present manuscript should be interpreted with caution. The sample is modest, the buildings are anonymized, and the field records were inherited from an existing draft rather than being generated anew during this rewrite. The contribution of this study lies in restructuring, correcting, and strengthening the code basis and the analytical presentation of the dataset, not in claiming a statistically exhaustive representation of all high-rise buildings in Indore.

CONCLUSION

This study demonstrates that a substantially improved research paper can be built from the retained 14-building dataset when the evaluation is re-centered on Indian Standards, NBC 2016, and an explicit mixed-occupancy logic. The strongest systems in the sample are portable extinguishers and selected water-based firefighting components, while the most serious shortfalls involve sprinklers, signage, assembly planning, disabled evacuation support, and firefighting/evacuation lifts. The core message is that fire safety optimization in high-rise buildings depends not only on installing components but also on ensuring that those components remain code-consistent, serviceable, accessible, and functionally integrated throughout the building life cycle.

Future Scope

Future work should extend the sample size and include additional Indian cities so that occupancy type, age profile, height, management model, and code-era differences can be compared more robustly. The second approach is to combine field audit data with evacuation simulation and smoke movement modelling to test how identified deficiencies translate into occupant risk under realistic fire scenarios.

The third opportunity lies in linking fire safety audits with digital assets and facility management. Building information modelling, QR-based equipment histories, automated maintenance logs, and zone-wise alarm analytics can help convert periodic inspections into a continuous reliability framework. Finally, future studies should explicitly examine inclusive evacuation design so that the needs of children, elderly occupants, patients, and persons with disabilities are treated as core fire and life safety parameters rather than residual considerations.

Future investigations can also integrate accessibility provisions from NBC Part 3 and lifecycle maintenance logic from NBC Part 12 so that evacuation support, wayfinding, and asset reliability are studied as a connected management system rather than as isolated design checks.

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