

A Comprehensive Fire Risk Analysis of Residential Building Through the Lens of Scenario Clustering

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Abstract- Fire accidents in residential buildings pose a significant threat, particularly in developing countries like India, where negligence and the failure to follow strict safety codes result in substantial loss of life and property damage. This project focuses on performing a comprehensive Fire Risk Analysis (FRA) of residential buildings by identifying and categorizing potential incidents into "scenario clusters". The study systematically identifies key risk factors such as building materials, design, and occupant behavior to evaluate fire risk levels. By examining specific scenarios—including electrical, cooking-related, and heating equipment fires—the project aims to assess the likelihood, severity, and potential spread of fire. Ultimately, the research provides actionable recommendations for improving fire prevention, protection, and emergency preparedness to create safer living environments.

I. INTRODUCTION

Residential Building Acc. To NBC 2016“These shall include any building in which sleeping accommodation is provided for normal residential purposes with or without cooking or dining or both facilities”.

Fire accident in residential buildings is a major threat for developing country. Developed countries have less building fire risk, compared to building of developing countries. In developed countries, fire safety rules, regulation, guidelines and codes are strictly enforced, therefore building owner ensures all Fire Safety related compliances, during building design, construction and later to control building fire risk.

Fire accident results in huge losses of lives and property damage. In India, each year fire accident occurs in several buildings occur due to negligence and not following strict safety rules of building by owner or occupants. Risk related to fire accident depends on factors such as type of building, fire load,

ignition sources, fire protection systems, occupant load and behaviour, escape routes, ventilation etc.

Fire risk analysis (FRA) of residential buildings aims to assess and manage fire risks through structured evaluations of potential fire scenarios and their consequences. When based on scenario clusters, FRA identifies representative fire situations and develops risk management strategies for each.

In this analysis, we will explore various fire accident scenarios in residential buildings, examining the primary causes of these incidents and identifying the safety measures and standards that were often neglected. By investigating case studies, we aim to highlight common shortcomings in fire prevention and response protocols. Furthermore, we will provide actionable suggestions for improving safety in residential settings, focusing on how to prevent such accidents and effectively manage them should they occur. Through this comprehensive examination, we hope to contribute valuable insights that can enhance fire safety in homes and protect lives.

Fire safety in residential buildings is a critical concern due to the high occupancy rates, the presence of vulnerable populations, and the potential for significant property damage and loss of life. Fires in such settings can be caused by various factors, including electrical faults, cooking-related incidents, human negligence, and the improper use of heating equipment. Given the diversity of fire risks, it is essential to adopt a systematic approach to fire risk analysis to ensure effective management and mitigation.

This project focuses on performing a fire risk analysis in residential buildings by identifying and categorizing potential fire incidents into specific

scenario clusters. Each cluster represents a group of similar fire risks that share common causes, likelihoods, and consequences. Key scenario clusters include:

- Electrical Fires
- Cooking related Fires
- Heating Equipment fires
- Human Negligence
- By analysing these scenario clusters, the project aims to assess the likelihood, severity, and potential spread of fire incidents in residential buildings. This analysis will consider several critical factors, such as:
 - Probability of Occurrence
 - Fire Spread Potential
 - Severity of Consequences
 - Detection and Evacuation Efficiency
 - Fire Suppression Effectiveness

The National Building Code (NBC) 2016

The National Building Code (NBC), developed by the Bureau of Indian Standards (BIS), provides comprehensive guidelines for building safety, health, and sustainability in India. Key revisions of NBC were introduced in 1970, 1983, 2005, and 2016, addressing advancements in technology, environmental concerns, and safety regulations. NBC 2016 is the most recent version. Key Provisions of NBC Relevant to Minor Projects are Fire and Life Safety (Part 3): Fire detection, suppression systems (sprinklers, alarms), and means of egress. Compartmentalization to prevent fire spread. Fire safety tailored for different occupancy types (residential, commercial). Relevance: Crucial for fire risk management projects. Structural Design and Seismic Safety (Part 5):

The International Building Code (IBC) is a globally recognized set of standards developed by the International Code Council (ICC) to ensure the safety, sustainability, and accessibility of buildings. The IBC provides comprehensive guidelines for the design, construction, and maintenance of various types of structures. This literature review highlights key aspects of the IBC relevant to fire safety and building design in a minor project context:

- Fire Safety Provisions

- Occupancy Classifications
- Means of Egress
- Structural Integrity During Fires
- Accessibility and Safety for All Occupants

This project review summarizes the National Electricity Code (NEC) 2023, which provides essential standards for electrical installations in India, ensuring safety, efficiency, and reliability.

- Key Points:
 - Scope and Applicability:
 - Applies to residential, commercial, industrial, and special occupancies, ensuring compliance with national safety standards.
 - General Safety Requirements: Emphasizes grounding, bonding, insulation, and the use of circuit breakers to prevent electric shocks and fires. Installation Standards:
 - Guidelines for wiring methods, conduits, and lighting systems, focusing on safety and energy efficiency.
 - Earthing Systems: Detailed requirements for proper grounding to prevent electric shock and ensure system safety.
 - Overcurrent and Overvoltage Protection: Mandates protective devices like circuit breakers and surge protectors to safeguard electrical systems.
 - Energy Efficiency: Promotes the use of energy-efficient designs and renewable energy systems, such as solar panels.
 - Special Occupancies: Specific provisions for hazardous environments to prevent fire and explosion risks.
 - Emergency Systems: Requirements for backup power sources and emergency lighting to ensure safety during outages.
 - Inspection and Testing: Requires periodic inspections and maintenance of electrical systems to ensure ongoing compliance with safety standards.
 - This review provides a concise overview of NEC 2023, serving as a vital resource for ensuring safe and efficient electrical installations.

Building bye laws are a set of regulations established by local authorities to control the construction,

design, and use of buildings within a jurisdiction. These rules ensure safety, functionality, and order in urban development. In a minor project, the study of building bye laws offers critical insights into:

Land Use and Zoning Regulations
Structural Safety
Fire Safety Provisions
Health and Sanitation
Environmental Considerations

Shahnawaz Rampuri, Fire Accident in Building of Developing Country, India [5]

In his study, Shahnawaz Rampuri focuses on the challenges and causes of fire accidents in buildings in developing countries, with a special emphasis on India. The literature highlights critical areas related to fire safety regulations, the impact of urbanization, and the role of technology in mitigating fire hazards. Below are the key points from the review:

- Electrical Failures
- Negligence and Human Error
- Building Materials
- Rapid Urbanization
- Lack of Compliance
- Insufficient Fire-fighting Resources
- Weak Enforcement
- Gap in Awareness
- Human Loss and Injury
- Economic Damage
- Fire Safety Education
- Technological Solutions

Jing Xin & Chongfu Huang, Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management [7]

Fire Risk Analysis of Residential Buildings Based on Scenario Clusters and Its Application in Fire Risk Management by Jing Xin & Chongfu Huang

This study by Jing Xin and Chongfu Huang focuses on a structured approach to fire risk analysis in residential buildings by identifying and categorizing potential fire hazards into scenario clusters. The method allows for a systematic evaluation of fire risks and enhances fire risk management.

The authors introduce the concept of scenario clusters, which group different fire causes and outcomes into categories for easier risk assessment. For example, fire scenarios can be categorized based on electrical malfunctions, cooking-related fires, or heating system failures. Each cluster is analysed for frequency, severity, and likelihood of occurrence.

The study proposes a quantitative approach to assessing fire risks by combining historical data with predictive models. This helps in estimating the probability of fire occurrences, potential damage, and impact on life safety for each scenario cluster.

By identifying specific fire scenarios, the analysis helps tailor fire prevention strategies and mitigation measures for residential buildings. It recommends improved fire detection systems, automatic fire suppression, and clear evacuation procedures to address high-risk clusters.

The study emphasizes that this method allows for more targeted fire safety measures, improving the effectiveness of fire risk management systems. It also enables resource allocation based on the most probable and severe risks, optimizing safety investments.

The authors acknowledge challenges, such as the need for comprehensive data collection and potential variability in fire risk based on building age, materials, and occupancy levels.

The scenario cluster approach introduced by Jing Xin and Chongfu Huang offers an innovative framework for fire risk analysis in residential buildings. This method enhances fire risk management by focusing on specific scenarios and providing actionable prevention strategies. This literature review is offering a structured approach to analysing and managing fire risks in residential settings.

Current Advances on the Assessment and Mitigation of Fire Risk in buildings and Urban -first edition by Tiago Miguel Ferrerira [8]

Minor Project on "Current Advances on the Assessment and Mitigation of Fire Risk in Buildings and Urban Areas—First Edition" by Tiago Miguel Ferreira

The paper by Tiago Miguel Ferreira explores the latest developments in fire risk assessment and mitigation strategies for both buildings and urban areas. It provides a thorough overview of modern techniques and tools to improve fire safety in residential, commercial, and urban environments. Key points include:

The paper introduces cutting-edge approaches like simulation models (e.g., fire spread simulations), risk mapping, and probabilistic assessments, which provide more accurate predictions of fire hazards in various types of buildings and urban layouts. These methods allow for a detailed understanding of how fire risk varies with building design, materials, occupancy levels, and environmental factors.

Urban Fire Risk Management: Ferreira emphasizes that fire risk mitigation should be a key component of urban planning. The study highlights the impact of population density, the proximity of buildings, and infrastructure limitations on fire risk. It also advocates for the design of urban areas with adequate fire escapes, emergency routes, and fire service accessibility in mind.

The paper outlines several mitigation strategies, including the use of fire-resistant materials, improved building compartmentalization, and sprinkler systems. The research also recommends incorporating passive fire protection measures during the design and construction phases to minimize the spread of fire.

Ferreira discusses the potential of technology in enhancing fire safety. The use of smart sensors for real-time fire detection, AI-driven analytics for risk prediction, and IoT-based systems for monitoring building conditions are highlighted as key advancements. These technologies not only improve fire detection but also facilitate faster response times by emergency services.

This paper is highly relevant for a minor project focusing on fire risk analysis and management in residential or urban contexts. It provides a comprehensive view of contemporary techniques and technologies that can be applied to assess fire hazards and develop more effective fire safety strategies. The

insights into urban planning and advanced risk assessment tools can be particularly useful for designing projects that aim to enhance fire safety in both individual buildings and larger communities.

GIDM, Handbook Series on Fire Safety Residential Buildings: A basic guide for Fire Prevention, Life Safety & Fire Protection requirements for the residential buildings [9]

The Gujarat Institute of Disaster Management (GIDM) handbook is a practical and comprehensive guide designed to improve fire safety standards in residential buildings. The handbook serves as a valuable resource for ensuring the implementation of fire prevention, life safety, and fire protection measures. The key elements covered in the guide include:

- Fire Prevention
- Life Safety
- Fire Protection Systems
- Compliance with Building Codes

In conclusion, this handbook is an essential tool for any project focusing on enhancing fire safety in residential buildings. Its clear and actionable guidelines on fire prevention, life safety, and fire protection systems make it a critical resource for ensuring that residential buildings are both compliant with safety regulations and equipped to manage fire emergencies effectively. For a minor project, this guide offers a solid framework for evaluating current fire safety measures and proposing improvements in residential buildings, particularly in densely populated urban areas where fire risks are higher.

Fire Risk Assessment and safety management in buildings and urban spaces – a new section of Fire Journal by Tiago Miguel Ferreria [10]

The research paper by Tiago Miguel Ferreira introduces an essential framework for fire risk assessment and safety management in both buildings and urban spaces, with a focus on improving fire safety through systematic analysis and innovative strategies. It emphasizes the importance of integrating fire risk assessments into urban planning and building design to mitigate fire hazards and ensure safety for occupants and the general public.

The study outlines methodologies to assess fire risks based on building types, occupancies, and environmental factors. It stresses the need for data-driven assessments to anticipate potential fire scenarios and their impacts.

The paper advocates for using specific fire scenarios (similar to scenario clusters) to tailor fire safety measures and response strategies.

The research extends beyond individual buildings, suggesting that fire risk assessments should be part of broader urban planning efforts to account for public spaces, fire escapes, and proximity to emergency services.

Ferreira encourages the use of modern technologies such as smart sensors, data analytics, and real-time monitoring systems to enhance fire detection and response capabilities.

The paper aligns well with the objectives of a minor project focused on fire risk analysis and management. It offers a detailed, practical approach to understanding fire hazards and developing effective prevention, detection, and evacuation strategies. This research can serve as a strong foundation for projects aiming to improve fire safety in residential buildings or broader urban environments.

An integral method for Risk Assessment in Residential Building by Hongfu Mi, Yaling Liu, Wenhe Wang, and Guoqing Xiao [11]

The paper proposes an integrated fire risk assessment method tailored specifically for residential buildings, combining both quantitative and qualitative approaches to enhance fire safety management. The approach consists of the following key elements:

The method begins by identifying common fire hazards in residential buildings, such as electrical faults, cooking-related fires, and human negligence. It also assesses critical areas within the building that are more vulnerable to fire, like kitchens, electrical rooms, and staircases.

A probabilistic model is used to quantify the likelihood of fire occurrences based on various

factors, including building design, occupancy patterns, fire safety systems, and historical fire data. This data-driven approach helps to calculate the overall risk level and prioritize areas that require attention.

The paper highlights the importance of using expert judgment to evaluate building-specific factors that quantitative models might overlook. This includes assessing emergency preparedness, the adequacy of evacuation routes, and the effectiveness of fire response measures (like alarms, sprinklers, and fire-fighting equipment).

By combining both quantitative risk data and qualitative expert assessments, the method produces a comprehensive fire risk profile for residential buildings. This integrated profile allows for more precise fire prevention strategies, improved evacuation planning, and better allocation of resources for fire safety improvements.

This integrated method is particularly valuable for minor projects focused on fire risk analysis in residential buildings. It offers a holistic approach that considers both measurable risks and expert insights, providing a well-rounded foundation for developing targeted fire prevention and mitigation strategies. It can also serve as a practical framework for improving fire safety standards and reducing fire-related risks in residential settings.

Fire Risk Analysis: Its Validity and Potential for Application In fire and safety AI SEKIZAWA [12]

Ai Sekizawa's paper critically examines the validity of fire risk analysis (FRA) and its potential applications in enhancing fire safety practices. The study presents a comprehensive overview of how fire risk analysis can be used to assess, predict, and mitigate fire hazards in various environments. Key points from the paper include:

Structured Fire Risk Analysis Framework: The research outlines the necessity of a systematic approach to fire risk assessment, which includes identifying fire hazards, estimating the probability of occurrence, and evaluating the consequences of fire incidents. Sekizawa stresses that FRA provides a risk-based perspective, which is essential for creating

effective fire safety measures tailored to specific environments.

Quantitative vs. Qualitative Approaches: The paper emphasizes that a robust fire risk analysis should combine both quantitative and qualitative methods. Quantitative models, such as fire behaviour simulations, probability calculations, and loss estimation, offer measurable insights into fire risks. On the other hand, qualitative assessments, based on expert judgment and regulatory guidelines, help account for factors that are harder to quantify, such as human behaviour and emergency response effectiveness.

Challenges and Limitations: Sekizawa discusses several challenges inherent in FRA, such as the lack of reliable data, the complexity of modelling fire dynamics, and the unpredictability of human behaviour in emergency situations. These challenges often limit the precision of fire risk models, highlighting the need for continuous improvement in data collection and risk assessment techniques.

Potential Applications in Fire Safety: The paper explores how fire risk analysis can be applied across multiple domains, including building design, evacuation planning, and regulatory compliance. FRA is particularly useful for designing fire safety measures that are specific to the characteristics of a building, such as its layout, materials, and occupancy. Additionally, FRA can inform emergency preparedness, ensuring that evacuation routes and fire response systems are optimized for real-world scenarios.

Sekizawa's work provides valuable insights for a minor project focused on fire risk analysis by offering both a theoretical foundation and practical considerations for its application. The study underlines the importance of using a risk-based approach to fire safety, making it highly relevant for projects aimed at improving fire prevention, mitigation strategies, and emergency response planning in residential or commercial settings.

Than Singh Sharma, *Fundamentals of Fire Safety in Building Design*, 2014 [15]

This project review focuses on the key concepts presented in Dr. Than Singh Sharma's work, which addresses the essential principles of fire safety in building design. Emphasizes the critical need for fire safety in buildings to protect lives, property, and ensure compliance with regulations. Discusses fundamental design strategies that enhance fire safety, including compartmentalization, means of egress, and fire-resistant materials. Highlights the role of early warning systems, such as smoke detectors and alarms, in alerting occupants and facilitating timely evacuation. Reviews various fire suppression methods, including sprinkler systems, fire extinguishers, and their integration into building design. Examines relevant codes and standards, such as the National Building Code (NBC), and their role in ensuring fire safety compliance. Advocates for conducting fire risk assessments to identify potential hazards and implement appropriate safety measures. Stresses the importance of designing buildings with occupant safety in mind, including accessible escape routes and signage. Highlights the necessity of training building occupants and staff on fire safety practices and emergency procedures. Dr. Sharma's work provides a comprehensive foundation for understanding fire safety in building design. This review serves as a valuable reference for a minor project at RGPV University, emphasizing the importance of integrating fire safety principles into architectural practices.

HSE Study Guide, *Tragic Fire in Kuwait Claims Lives of 45 Indian Workers* [16]

- On June 12, 2024, a devastating fire broke out labour accommodation in Mangaf, Kuwait.
- Claiming life of 45 Indian workers (23 from Kerala, 7 from Tamil Nadu, 3 from Andhra Pradesh, 1 from Bihar, Odissa, Karnataka, Maharashtra, Uttar Pradesh, Jharkhand, Haryana, Punjab, West Bengal)
- 3 Filipino also lost their lives.
- Due to the damage caused on the deceased's bodies Kuwait authorities conducted DNA tests on them to confirm their identities.
- The remains were handed over to the Indian officials to facilitate the repatriation.
- The Kuwait Fire Force confirmed that the fire was caused by electrical circuit malfunction.

- This conclusion was reached after a thorough investigation of the incident site.
- The fire engulfed the Al-Mangaf building in the Al-Ahmadi governorate and was reported to the authorities at 04:30 on Wednesday.
- KC Eappen, The Director of Indian operation for NBTC Group (Naser M. Al Baddah & Partner General Trading and Contracting Company)
- In response, company announced compensation of 8 lakh INR to each family of the deceased and 2 Lakh INR to those injured and covered all the medical expenses for the injured worker.
- 33 Indian workers were hospitalised.

This tragic fire in Kuwait claimed the lives of 45 Indian workers and injured 33 of them which highlights the critical needs for safety measures in labour accommodations. Implementing regular inspection, comprehensive fire safety systems, emergency preparedness and through training can prevent such disasters.

II. OCCUPANCY INTRODUCTION

Occupancy plays a critical role in fire risk analysis, particularly in residential buildings. Understanding how people interact with their living environments is essential for identifying potential fire hazards and developing effective fire risk management strategies. This project focuses on various types of residential occupancy, including single-family homes, multi-family units, and apartment complexes, each presenting unique challenges and risks.

In residential settings, occupancy patterns can significantly influence fire risks. Factors such as the number of residents, their daily routines, and their familiarity with fire safety measures are crucial to understanding how fires can start and spread. For instance, high-density housing may increase the likelihood of fire incidents due to shared walls and common spaces, while single-family homes may present different challenges based on individual lifestyles and safety practices.

Additionally, the demographics of occupants, including age, mobility, and awareness of fire

hazards, play a significant role in fire risk. Young children and elderly residents, for example, may require different safety considerations and evacuation strategies. Cultural factors and socioeconomic status also influence fire safety behaviours, as access to resources and education about fire risks can vary widely among different communities.

This project aims to analyse how these occupancy factors relate to specific fire scenarios, clustering them to identify common risks and effective management strategies. By focusing on the interplay between occupancy and fire risk, we can develop targeted interventions that enhance fire safety and reduce the likelihood of residential fires. Understanding these dynamics is essential for creating a comprehensive framework for fire risk management that prioritizes the safety and well-being of all residents.

Description of Fire Behaviours of Structural Materials

Fire behaviour of structural materials is important from the perspective of structural safety. The materials could undergo physical and chemical changes that may affect the stability of the structure. The physical change of structural components relates to density variation such as softening, melting or spalling. Chemical change relates to decomposition and charring. Thermal conductivity and specific heat determine the thermal properties of a material. Thermal conductivity determines the rate of heat transfer in the materials, whereas specific heat provides the heat absorption capacity of a material for a given rise in temperature. Several materials are used in the construction of buildings and properties of some of the common materials are given here:

- Brick
- Steel
- Unstressed and Stressed Concrete
- Stone
- Aluminium
- Glass
- Wood
- Plastics

Classification of Occupancy

According to NBC 2016, Chapter IV, all buildings, whether existing or hereafter erected shall be classified according to use or the character of occupancy in one of the following groups:

- Group A Residential
- Group B Educational
- Group C Institutional
- Group D Assembly
- Group E Business
- Group F Mercantile
- Group G Industrial
- Group H Storage
- Group J Hazardous

Group A Residential Buildings

These shall include any building in which sleeping accommodation is provided for normal residential purposes with or without cooking or dining or both facilities, except any building classified under Group C. Buildings and structures under Group A shall be further subdivided as follows:

- Subdivision A-1 Lodging and rooming houses
- Subdivision A-2 One- or two-family private dwellings
- Subdivision A-3 Dormitories
- Subdivision A-4 Apartment houses
- Subdivision A-5 Hotels
- Subdivision A-6 Starred hotels

Description of Various Concepts

- Smoke and Heat Exposure
- Building Evacuation
- Human Psychological Behaviour
- Concentrated Fire Load
- Fire Fighting Operations
- Structure Failure
- Fire Risk Management
- Fire Risk Analysis Method
- Quantitative Methods

Types of Buildings

Type 1 (443 and 332) constructions are selected because they provide reasonable fire safety for the structure for occupancies with moderate and low combustible contents. The occupancies of higher fire loads and hazardous uses, fire resistance may be supplemented by additional fire protection measures.

The occupancies like mercantile, some industrial premises and storage uses are provided with Type I construction along with additional fire protection measures. Non-combustible materials are only allowed for the structural elements of the buildings.

Type II (222 and 111) construction are selected for residential, educational, institutional, business and assembly occupancies without additional fire safety provisions. Sometimes, additional fire safety measures are required for the occupancies having higher fire load. Non-combustible materials are only permitted to use in the buildings.

Type III (211 and 200) construction includes all or parts of the building structural elements as combustible. The exterior wall is required to be non-combustible, whereas interior structural elements may be of combustible materials. It is further divided into protected and unprotected sub-types. Type (211) construction has 1 (one) hour fire resistance for the floor as protected structural element. Type (200) construction has no fire resistance for the floors and therefore falls under unprotected sub-type.

Type IV (2HH) is a type of construction in which all the structural elements such as column, beams, girders, arches, floors, roofs are unprotected wood but of larger cross-sectional areas. No concealed spaces are permitted in the structure.

Type V (111) construction has all the structural members of wood. Depending upon the exterior open space, exterior walls may or may not be of required fire resistance. It gives least fire resistance and hence most vulnerable to fire. Therefore, the concept of fire compartment along with the fire stoppers envisaged to retard the fire for a particular duration. Type (111) construction has one-hour fire resistance throughout, and Type (000) construction has no fire resistance requirements.

According to NBC (Part IV), 2005 classifications, the types of construction are classified into four categories namely Type 1 Construction, Type 2 Construction, Type 3 Construction and Type 4 Construction.

Automatic Sprinkler System

The sprinkler system is designed to control a fire without human activity. It is especially useful in unattended buildings. The sprinkler system consists of pipe layout designed hydraulically to provide the required amount of water at a particular design pressure. The pipes are suspended or embodied under the ceiling with opening at regular interval that sealed with thermally operated sprinkler heads. Sprinklers are mounted on pipe work beneath the ceiling of the protected risk and operated in fire condition. Sprinklers are operated automatically by means of melting fusible elements or breaking of frangible glass bulb. The fusible element or glass bulb acts like a plug for the pressurized water in the piping system. Once this plug breaks, the water shoots out from the sprinkler. The sprinkler system is designed to spread out the water falling over the fire. The pipes distributing the water are constantly under pressure. The network of pipe is connected to the common riser. Pumps are used to maintain the pressure in the system.

demand of sprinkler heads in the fire zone. These pumps operate automatically when the pressure falls at a pre-determined level through the pressure switches.

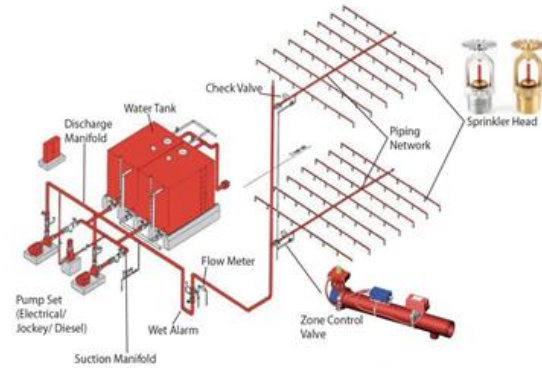


Fig: General Layout of Automatic Sprinkler System.

Problem Formulation

Legal Parameters

NBC, 2016 (Chapter IV)

Since the sprinkler system serve unattended areas, it is important that humans can be alerted whenever sprinkler is activated. For this purpose, flow switches are installed at each sprinkler zone. Whenever a sprinkler is activated, water flows out from the pipes to the sprinkler head. The flow of the water through a zone pipe activates a flow switch. The electrical signal from the flow switch activates an alarm at the main fire alarm panel. Each zone is provided with an isolation valve, a flow switch and a test drain valve. Depending on the size of the building, there may be several water riser pipes supplying to all the floors of a building. Pressure gauges, check valves and alarm gongs are installed in each riser. The alarm gong is actuated by the flow of water through the check valve and not by electrical signal of the individual sprinkler zones. Normally, the sprinkler system is fed from the underground water storage tank and dual supply is maintained from the overhead water storage tank. The water supply from the tank is generally provided in such a manner to give positive pressure to the pump suction side. Fire brigade connection is provided on the installation to facilitate the fire brigade appliances to provide water to sprinkler heads. The pumps are designed to supply required quantity of water at a particular design pressure. The pumps are installed in series to meet the increasing

Sr. No.	Residential Building (Note 5)	Type of Installation							Water Supply (Litres)		Pump Capacity (litre/minute)		
		Fire Extinguisher	First Aid Hose Reel	Wet Riser	Down Comer	Yard Hydrant	Automatic Sprinkler System	Manually Operated Electronic Fire Alarm System (Note 1)	Automatic Detection System (Note 2)	Underground storage tank per set of pumps	Terrace tank over storage tank (minimum 3.5 bar pressure at remotest point)	Pump near underground storage tank with minimum 3.5 bar pressure at remotest point	Pump at terrace tank with minimum 3.5 bar
a)	Lodging and Rooming Houses (A-1)												
1.	Less than 15 m in height												
i.	Up to 15 rooms	R	NR	NR	NR	NR	R (Note 3)	NR	NR	NR	(5000) Note 3	NR	NR
ii.	More than 15 and up to 30 rooms	R	R	NR	NR	NR	R (Note 3)	NR	NR	NR	5000 (5000) Note 4	NR	450 (450) Note 4
iii.	More than 30 rooms	R	R	NR	NR	NR	R (Note 3)	R (Note 10)	NR	NR	10000 (5000) Note 4	NR	450 (450) Note 4
b)	One or Two Family Private Dwellings (A-2)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

- As shown in Table 4.1., Lodging and Rooming houses (A-1) even of Less than 15m in height in all the category of ‘Less than 15 rooms’, Fire extinguishers and Automatic Sprinkler System are required to be installed but its very uncommon to see these two installations on them mostly for cost efficient reasons and still these buildings get Fire & Safety clearance.
- As shown in Table 4.1., Lodging and Rooming houses (A-1) even of Less than 15m in height in all the categories of ‘More than 15 rooms up to 30 rooms’ as well as ‘More than 30 rooms’, Fire extinguishers and Automatic Sprinkler System along with First Aid Hose Reel are required to be installed but it’s very uncommon to see all of these installations on them mostly for cost

efficient reasons and still these buildings get Fire & Safety clearance.

- As we are stressing upon the safety of non-high-rise buildings in this project we couldn't ignore the fact that NBC 2016, Chap. IV (as shown in above table) clearly mentions that Fire Extinguishers along with First Aid Hose Reel and Automatic Sprinkler System are required to installed in Dormitories(A-3) and Apartment Houses (A-4) of 'Less than 15m in height', which are rare to see in the Apartments and Dormitories around us which clearly indicates the ignorance and irresponsibility of the Owner of that building as well as the Local Fire & Safety Department who give these buildings clearance to operate in such unsafe conditions which clearly increases the risk for the people living in such buildings and also to the general public which can get affected.

No.	Residential Building (Clause 3)	Type of Installation							Water Supply			Pump Capacity		
		Fire Alarm	First Aid Hose Reel	Hand Hose	Fireman's Ladder	Hand Firefighting	Automatic Fire Extinguisher	Automatic Fire Extinguisher	Automatic Fire Extinguisher	Automatic Fire Extinguisher	Automatic Fire Extinguisher	Automatic Fire Extinguisher	Automatic Fire Extinguisher	Automatic Fire Extinguisher
1	Apartment House (A-3) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Apartment House (A-4) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Apartment House (A-5) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Apartment House (A-6) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Apartment House (A-7) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Apartment House (A-8) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Apartment House (A-9) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Apartment House (A-10) of less than 15m in height	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

A fire event is an occurrence that is related to fire initiation, or fire growth, or smoke spread, or occupant behaviour, or fire department response. In the process of understanding fire risk analysis, three fire scenario clusters can be considered important to support calculations of frequency and consequence: namely a fire scenario cluster, a fire automatic suppression scenario cluster, and a behaviour cluster. The fire scenario cluster must specify all the elements including design fire curve and as well many other surrounding circumstances of the fire, such as compartment geometry and properties, dimensions of the fire origin room, the thermal properties of the compartment boundaries.

Present Research work under project title "Fire Risk Analysis of Residential Buildings based on Scenarios Cluster and its Application on Fire Risk Management" we came across a Research Paper developed by two Chinese Researchers named 'Jing Xin' and 'Chongfu Huang' from Academy of Disaster Reduction and Emergency Management, Beijing Normal University, Beijing 100029, PR China and Department of fire command, Chinese People's Armed Police Force Academy, Langfang 065000, PR China has done a remarkable job by developing this research paper which clearly has a lot of insight on the title along with the definition of Design of Scenario Cluster as well as various Quantitative Methodology that can be used to evaluate any residential buildings hazards. Their research includes:

Design fire curve is meant that fire growth rate and other specification, such as the point of fire origin, are required for a full description.

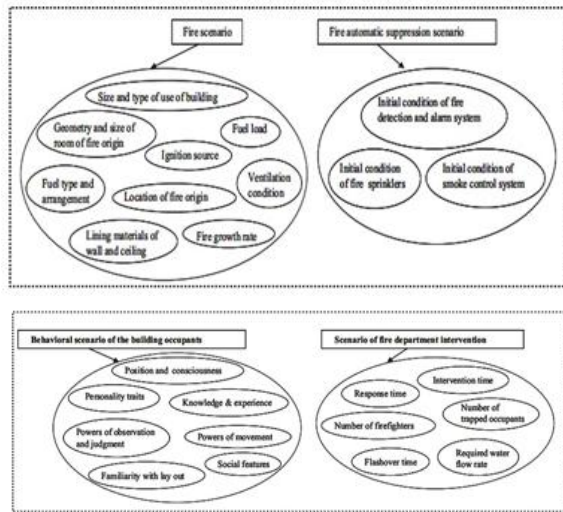
Design of Scenario Clusters:

A 'fire scenario cluster' is a subset of fire scenarios that resembles each other. It could group the universe of possible fires into a manageable number of scenario subsets so that all the elements are present. A fire scenario is a sequential set of fire events that are linked together by the success or failure of certain fire protection systems or actions.

The fire automatic suppression scenario cluster describes the process of fire repression, either through the extinguishing of the fire or the control of the fire from further progress using for example knowledge of construction engineering. Initial status of fire detection and alarm equipment, fire sprinklers, smoke control systems all would be included, and they could induce different fire suppression scenarios.

The principal elements a fire scenario and a fire automatic suppression scenario are shown in Fig. 4.3 The behaviour scenario cluster describes the behaviour of occupants in response to the onset of the fire and the intervention of fire and rescue services in the case of building fires. The location, personality traits, knowledge and experience, powers of observation and judgment, mobility, awareness, roles or responsibilities in buildings, and familiarity with the layout of buildings all influence occupants' behaviours. Major factors influencing fire brigade intervention are intervention time, crew size and fire-fighting water resources. Elements of behavioural

scenarios of occupants in buildings and fire department intervention as shown in Fig 4.4.



Research Gape between existing work and proposed work

Present Research work under project title “Fire Risk Analysis of Residential Buildings based on Scenarios Cluster and its Application on Fire Risk Management” a Research Paper developed by two Chinese Researchers named ‘Jing Xin’ and ‘Chongfu Huang’ from Academy of Disaster Reduction and Emergency Management, Beijing Normal University, Beijing 100029, PR China and Department of fire command, Chinese People's Armed Police Force Academy, Langfang 065000, PR China lacks the following points:

- Various kinds of scenario clusters that could be developed by them using the insights on the topic in brief.
- The Research Paper in based on the Standards and Parameters set by the Chinese Government and does not apply here in India so it can't be of too much help and provides us this opportunity to develop this project that can be helpful for the Safety of Residential Buildings in India.
- Our project includes various scenario clusters that can be very helpful in analysing the problems that can cause serious harm to the residents as well as to the public. These scenarios include various key factors that can affect the potential of harm caused during those scenarios and also the mitigation measures that can be very helpful for the occupancies during such situations.
- Our project includes various Statistics of the

data present on the internet about he fires accidents caused in the Residential Buildings in India along with the data about how they are cause (ignition source) and how it can be prevented with active and passive measures.

- Our project includes a vast description about the Fire Behaviour of Structural Material used in construction of such buildings which can be a crucial factor while analysing such scenarios. This was another factor that was absent in the previous work on this title.
- This project includes various facts and figures along with the legal standards and parameters set by the Indian Governments such as the tables mentioned in NBC 2016, Chapter IV and the statistics provided by National Crime & Research Bureau (NCRB) about the fire accidents occurred in India during the time period of 2008 to 2018 as well as the percentage shares in Death caused by Fire in Residential Buildings.
- This Project includes various conceptual theories such as Smoke and Heat Exposure, Influence of External Factors (Stack effect), Building Evacuation, Human Psychological Behaviour, Concentrated Fire Load, Locating the Fire, Fire Fighting Operations, Structure Failure, Fire Risk Management, Fire Risk Analysis Method, Ranking Method, Acceptable level of risk, Types of Building and Automatic Sprinkler System. All these theories can be very helpful to raise public awareness about the risks present in Residential buildings and how these risks can be mitigated by having a general understanding of these concepts.

Equation /Statement of Problem for which project is proposed

Fire safety in residential buildings is a critical concern, particularly in non-high-rise buildings where inadequate fire safety installations can significantly elevate fire risks. Unlike standardized high-rise buildings, which are mandated to comply with strict fire safety codes, non-high-rise residential buildings often lack essential fire protection measures, such as automatic sprinkler systems, compartmentalization, and adequate escape routes. This disparity necessitates a thorough fire risk analysis based on scenario clusters to assess vulnerabilities and propose effective fire risk management strategies. Problem Statement

The primary objective of this study is to quantify and compare the fire risk levels in standardized high-rise buildings and non-high-rise residential buildings with

inadequate fire safety measures. The absence of robust fire protection installations in non-high-rise structures leads to an increased probability of fire ignition, rapid fire spread, and severe casualties or property damage. The study aims to develop a fire risk analysis model based on scenario clusters that can be applied to fire risk management in such vulnerable buildings.

To mathematically represent the problem, let:

- FR_H = Fire Risk Index for a standardized high-rise building
- FR_{NH} = Fire Risk Index for a non-high-rise residential building (without adequate fire safety)
- FSI = Fire Safety Installation Index (a measure of fire safety provisions)
- P(FI) = Probability of fire ignition
- P(FS) = Probability of fire spread beyond the point of origin
- C = Consequence factor (loss of life, property damage, etc.)

We hypothesize that:

$FR_{NH} = f(P(FI), P(FS), C, FSI)$
 $FR_{NH} > FR_H$

where FSI for non-high-rise buildings is significantly lower than that for standardized high-rise buildings, leading to:

$FR_{NH} > FR_H$
 $FR_{NH} > FR_H$

CH -05 Material and Methodology

Fire safety is a critical aspect of building design, particularly in residential structures where the risk to human life is significantly high. The severity of fire incidents depends on various factors, including building height, occupancy type, fire safety installations, and emergency response mechanisms. High-rise buildings, due to their complexity and population density, are typically subject to stringent fire safety regulations, while non-high-rise residential buildings often lack adequate fire safety installations, leading to increased fire risks.

The objective of this study is to analyze fire risk in non-high-rise residential buildings using scenario clusters and to compare their risk levels with standardized high-rise buildings that comply with fire safety regulations. By leveraging fire risk management frameworks and regulatory standards, this study aims to propose measures for improving fire safety in vulnerable residential structures.

Fire Safety Standards and Regulations

Indian Standards and Regulations

In India, fire safety in buildings is governed by various codes and regulations issued by national agencies such as the Bureau of Indian Standards (BIS), the National Building Code of India (NBC), and state-specific fire services. Key regulations include:

National Building Code of India (NBC), 2016:

- NBC Part 4 provides guidelines on fire protection, covering aspects such as building classification, fire resistance, means of escape, fire detection, and suppression systems.
- It mandates automatic fire detection and alarm systems for high-rise buildings (above 15 meters in height).
- Non-high-rise residential buildings, particularly low-rise apartments and single-family homes, are often exempt from stringent fire protection measures.

Bureau of Indian Standards (BIS) Codes:

- IS 1641: 1988 – Code of practice for fire safety in buildings (General principles of fire grading and classification).
- IS 1642: 1989 – Code of practice for fire safety in buildings (Details of means of escape).
- IS 2189: 2008 – Code of practice for selection, installation, and maintenance of automatic fire detection and alarm systems.

State Fire Safety Regulations:

- Fire safety measures are enforced by state fire departments through local bylaws and building approval processes.
- While commercial and high-rise buildings undergo mandatory fire safety inspections, low-rise residential buildings frequently lack regulatory oversight.

International Standards and Regulations:

Globally, fire safety in buildings is regulated by comprehensive codes and standards to ensure occupant protection. Some of the key international standards include:

1. National Fire Protection Association (NFPA), USA:

- NFPA 101: Life Safety Code – Establishes minimum requirements for the design, operation, and maintenance of buildings for fire safety.
- NFPA 13: Standard for the Installation of

Sprinkler Systems – Mandates automatic sprinklers in residential buildings exceeding three stories.

- NFPA 72: National Fire Alarm and Signaling Code – Defines requirements for fire alarm and detection systems.

2. International Building Code (IBC), USA:

- Requires automatic sprinkler systems in buildings taller than 75 feet.
- Establishes fire resistance ratings for walls, floors, and structural components.

3. European Standards (EN Codes):

- EN 54: Fire Detection and Fire Alarm Systems – Regulates fire alarm systems in buildings. EN 12845: Automatic Sprinkler Systems – Specifies requirements for automatic fire suppression.
- Fire-resistant construction and compartmentalization are emphasized to prevent fire spread.

Research Approach

This study will employ a structured methodology to assess fire risk in non-high-rise residential buildings, including:

- Collection of real-world fire incident data from government agencies and fire departments.
- Surveys and interviews with residents and fire safety professionals to gauge preparedness levels.
- Comparative analysis of high-rise and non-high-rise buildings based on fire safety compliance and incident records.
- Mathematical modeling of fire risk scenarios, incorporating fire spread, response time, and safety installations.

5.2 Data obtained from Occupancy

Data obtained from Occupancy:

Occupant load refers to the maximum number of people allowed in a building or specific area based on its design and intended use. It is a critical factor in fire safety, ensuring safe evacuation in case of an emergency. Authorities calculate occupant load to prevent overcrowding and ensure compliance with building and fire codes.

Calculation of Occupant Load

The occupant load is determined using formulas set by building and fire codes, such as the National Fire Protection Association (NFPA 101 - Life Safety Code) and the International Building Code (IBC). The general formula used is:

The Occupant Load Factor varies based on the type of occupancy. For example:

- Assembly areas (without fixed seats) – 15 sq. ft. per person
- Business areas – 100 sq. ft. per person
- Residential areas – 200 sq. ft. per person

Mercantile (Retail) – 30 sq. ft. per person

Importance of Occupant Load in Fire Safety

- Safe Evacuation: Proper occupant load calculations ensure that all occupants can exit safely without congestion during emergencies.
- Fire Protection Compliance: Adhering to occupant load limits helps maintain compliance with fire safety codes and reduces liability.
- Preventing Structural Overload: Buildings are designed with load limits, and exceeding them can lead to structural hazards.
- Emergency Planning: Accurate occupant load assessments contribute to better emergency response planning and fire drills

Strategies for Managing Occupant Load

- Regularly review and update occupancy calculations based on renovations or space reconfigurations.
- Clearly post Occupant Load Signage at entrances to assembly areas.
- Train employees and safety personnel to monitor and control crowd density.
- Ensure exit pathways and fire escapes are unobstructed and adequately sized for the calculated occupant load.

Data Analysis/Assessment

This chapter analyzes the probability of fire-related accidents occurring within residential buildings, focusing on Sarova Towers, Yashraj Residency, and Tuli Parisar. The analysis considers fire safety measures, occupant awareness, hazard indices, maintenance practices, and building occupancy. The results obtained represent the chances of a fire-related accident occurring in one year, expressed as a percentage, providing valuable insights into the effectiveness of existing safety protocols.

Checklist for Inspection in Occupancy

1.	Name of the Occupancy	Sarova Complex
2.	Address of the Occupancy	Sarova Rd, Phase 1, Samata Nagar, Singh Agri Estate, Kandivali East,

		Mumbai, Maharashtra 400101	
3.	No. of Floors	G+33	
4.	Date of Inspection	01/03/26	
S. no.	Description	Yes	No
1.	Evacuation plan Available	(✓)	
2.	No. of exits >=2	(✓)	
3.	Unit width of exit >=50cm	(✓)	
4.	Maximum travel distance of passage way in a building <=22.5m	(✓)	
5.	Unit width of the passage way >=1.5m	(✓)	
6.	Availability of emergency lightening	(✓)	
7.	Availability of backup power source	(✓)	
8.	Width of staircase >= 1.5m	(✓)	
9.	Availability of fire extinguisher	(✓)	
10.	Availability of sprinklers	(✓)	
11.	Occupants trained for emergency evacuation	(✓)	
12.	Availability of medical aid	(✓)	
13.	Artificial Ventilation	(✓)	
14.	Adequate measures for detection and alarming in case of emergency situation	(✓)	
15.	Person allotted for proper conduction and evaluation of emergency evacuation procedure	(✓)	
16.	Exit provide means of access to the exterior of building	(✓)	
17.	Availability of signage for exits	(✓)	
18.	False Ceiling and false floor are made of non-combustible material	(✓)	

19.	Required PPE availability	(✓)	
20.	Overcurrent Protection	(✓)	
21.	Opening of gate in outward direction	(✓)	
22.	Availability of fire-resistant door	(✓)	

Sarova Complex

To calculate the probability of fire-related accidents in Sarova Complex, we will consider several factors based on available data and general fire safety statistics. Here's the approach:

Approach: Probability Calculation

Factors to Consider:

Fire Safety Measures Efficiency (FSME): How effective are the implemented safety measures.
Occupant Awareness (OA): Level of awareness and training among residents. Historical Data (HD): General fire accident data in residential high-rise buildings. Building Occupancy (BO): Number of occupants that may increase the risk.

Fire Hazard Index (FHI): Based on combustible materials and structural resilience.

Inspection and Maintenance Frequency (IMF): How regularly safety systems are checked and maintained. Formula to Estimate Probability:

$$P(\text{Fire Accident}) = \frac{(1 - \text{FSME}) \times (1 - \text{OA}) \times \text{FHI} \times (1 - \text{IMF}) \times \text{BO}}{\text{Average Safety Score}}$$

- Fire Safety Measures Efficiency
- Occupant Awareness
- Fire Hazard Index
- Inspection and Maintenance Frequency
- Building Occupancy

Estimating Each Factor for Sarova Towers:

1. Fire Safety Measures Efficiency (FSME)

Given that Sarova Towers has extensive safety measures (sprinklers, extinguishers, alarms, fire-resistant doors), we estimate FSME at 0.95 (95% efficiency).

2. Occupant Awareness (OA)

As residents are trained for emergency evacuation, the awareness level is high: 0.90.

3. Fire Hazard Index (FHI)

Due to non-combustible materials and structural integrity, FHI is 0.05.

4. Inspection and Maintenance Frequency (IMF)

Regular maintenance and documented checks give an IMF of 0.90.

5. Building Occupancy (BO)

Considering a high-rise with approximately 200 apartments, averaging 4 residents per unit:

$$BO = 200 \times 4 = 800$$

6. Average Safety Score:

A well-maintained and modern high-rise has a typical safety score of 0.85.

Calculating the Probability:

Substituting the values:

$$P(\text{Fire Accident}) = \frac{(1 - 0.95) \times (1 - 0.90) \times 0.05 \times (1 - 0.90) \times 800}{0.85}$$

$$P(\text{Fire Accident}) = \frac{0.05 \times 0.10 \times 0.05 \times 0.10 \times 800}{0.85}$$

$$P(\text{Fire Accident}) = \frac{0.000025 \times 800}{0.85}$$

$$P(\text{Fire Accident}) = \frac{0.02}{0.85} = 0.0235 \approx 2.35\%$$

III. CONCLUSION

The probability of a fire-related accident occurring in Sarova Towers in one year is approximately 2.35%.

This low probability highlights the excellent safety standards and preventive measures in place, significantly minimizing fire risks.

CH -06 Observations, Result summary and Discussion

Observation:

During the course of our project on Fire Risk Analysis of Residential Buildings and Scenario Cluster Development Based on Risk Analysis, we have identified several critical shortcomings in the implementation and adherence to fire safety regulations in residential buildings across India. Fire safety in residential buildings is governed primarily by the National Building Code (NBC) Part 4 on Fire and Life Safety, which provides comprehensive guidelines for fire prevention, suppression systems, emergency response planning, and evacuation procedures. Despite the existence of these well-established standards, our observations highlight a consistent pattern of non-compliance, poor enforcement, and lack of awareness among both residents and building management authorities. One of the most alarming issues we identified is the widespread non-compliance with the NBC's

structural and fire protection requirements. Many residential buildings fail to meet the minimum fire safety standards, especially in terms of fire exits, escape routes, and fire suppression infrastructure. Emergency exits are frequently obstructed, inadequately marked, or altogether absent, making it difficult for residents to evacuate safely during an emergency. Stairwells and escape routes are often used for storage or other non-intended purposes, further increasing the risk of injury or fatalities during a fire incident. In several cases, building designs do not incorporate separate fire escape staircases, which is a clear violation of NBC norms.

In addition to inadequate structural provisions, the installation and maintenance of fire suppression systems are severely lacking. Fire hydrants, sprinklers, and alarm systems are either not installed at all or are non-functional due to poor maintenance. The NBC mandates that fire suppression systems, including sprinklers and fire extinguishers, should be inspected regularly and maintained in proper working condition. However, in most residential buildings, these systems are installed only to meet initial regulatory approvals and are subsequently neglected. Fire extinguishers are often found to be expired or insufficient in number, while water supply lines connected to fire hydrants are sometimes dry due to poor maintenance. Sprinkler systems, where installed, are rarely subjected to regular flow tests, leading to reduced reliability during emergencies. The issue of occupancy load and escape route standards also remains a serious concern. The NBC specifies the maximum allowable occupancy load for different types of residential buildings and the required width and number of exit routes based on building height and occupant capacity. However, we observed that many residential complexes exceed the permissible occupancy limits, leading to overcrowding and increased risk during evacuation. Staircases and corridors are often narrow, congested, or blocked, making it difficult for residents to exit the building in an orderly manner during a fire. The absence of clear and illuminated exit signs further compounds the problem, as residents may struggle to locate escape routes in low-visibility conditions caused by smoke or power failures.

Another significant shortcoming is the lack of awareness and preparedness among residents and building staff regarding fire emergencies. Regular fire drills and emergency response training sessions are required under the NBC and local fire department guidelines to ensure that residents know how to respond effectively in the event of a fire. However, in most residential buildings, fire drills are either not

conducted or are treated as a mere formality without proper resident participation. Building staff, including security personnel and maintenance staff, are often not trained in the use of fire-fighting equipment or in managing crowd control during an emergency. This lack of preparedness increases the potential for panic and confusion, further complicating evacuation efforts and increasing the risk of casualties.

Electrical safety standards are also frequently disregarded, contributing to a high incidence of electrical fires in residential buildings. Faulty wiring, overloaded circuits, and poor-quality electrical fittings are common problems. The NBC outlines specific electrical safety measures, such as the use of circuit breakers, proper earthing, and high-quality wiring materials, but these guidelines are often ignored during construction and maintenance. Temporary electrical connections and the use of low-quality extension cords are widespread, further increasing the risk of electrical fires. In several cases, fires have been traced back to poorly maintained electrical panels or short circuits caused by overloading. Furthermore, the enforcement of fire safety regulations by local authorities remains inconsistent and ineffective. While building permits and occupancy certificates are supposed to be issued only after ensuring compliance with fire safety standards, many residential buildings are granted approvals despite glaring safety violations. Regular inspections by fire departments are rare, and even when violations are identified, corrective actions are not enforced promptly. In cases where fines or penalties are imposed, they are often too small to serve as a meaningful deterrent. This lack of accountability allows builders and property management authorities to prioritize cost savings over resident safety. Our analysis underscores that while India has a robust legal framework for fire safety through the NBC and state-level fire codes, the actual implementation of these regulations is far from satisfactory. The gap between regulation and practice arises from a combination of weak enforcement, poor infrastructure, and a general lack of fire safety awareness among residents and building managers. Strengthening the enforcement mechanism is crucial to improving fire safety outcomes. This can be achieved by increasing the frequency and rigor of inspections, imposing stricter penalties for non-compliance, and encouraging proactive maintenance of fire safety equipment. Moreover, increasing public awareness through fire safety education campaigns and resident training programs can help create a culture of safety and preparedness.

In conclusion, our project highlights that fire safety in residential buildings in India remains compromised due to poor compliance with existing regulations, inadequate maintenance of fire suppression systems, and lack of preparedness among residents and building staff. Addressing these challenges requires a multi-pronged approach that includes stricter enforcement, improved infrastructure, and increased awareness.

Ensuring that residential buildings meet NBC standards and that residents are prepared to respond effectively during fire emergencies can significantly reduce the risk of fire-related injuries and fatalities, ultimately creating safer living environments.

Result obtained and its interpretation:

Sarova Towers: The probability of a fire-related accident occurring in one year is 2.35%. This low probability reflects the comprehensive fire safety systems in place, including automatic sprinklers, fire-resistant doors, advanced detection systems, and well-trained occupants. The robust maintenance protocols and adherence to both Indian and international standards contribute to its exemplary safety profile.

Interpretations:

The results clearly indicate that fire safety measures, regular maintenance, and occupant preparedness are crucial in minimizing fire risks. High-rise buildings like Sarova Towers benefit significantly from comprehensive safety systems and regular drills, while low-rise structures require targeted improvements, particularly in training and fire suppression systems. The inclusion of modern technologies, like solar panels at Yashraj Residency, showcases how sustainability can also contribute to safety. Enhancing fire safety awareness and systematically upgrading older buildings will be vital in reducing fire risks across residential environments.

Important finding and conclusion:

As part of our project titled "Fire Risk Analysis of Residential Buildings and Scenario Cluster Development Based on Risk Analysis," we conducted an in-depth study of fire safety measures and compliance levels in residential buildings. Our investigation focused on assessing whether the existing fire safety standards, particularly those outlined in the National Building Code (NBC) Part 4 on Fire and Life Safety, were being effectively implemented in residential buildings. Through site visits, data collection, and analysis of past fire incidents, we identified several key shortcomings and areas of concern.

Important Findings:

Non-Compliance with NBC Standards:

Many residential buildings do not comply with the minimum fire safety requirements outlined in NBC Part 4. Essential fire protection measures such as properly marked fire exits, separate fire escape staircases, and adequate escape routes are often missing. The building designs frequently fail to accommodate essential fire safety features, increasing the risk of casualties during an emergency.

Inadequate Fire Suppression Systems:

Fire extinguishers are often either absent, expired, or insufficient in number. Sprinkler systems and fire hydrants are poorly maintained or non-functional due to lack of proper inspections and maintenance. Fire alarms and smoke detectors, where installed, are not regularly tested or are found to be malfunctioning.

Blocked and Insufficient Escape Routes:

Emergency exits and staircases are often blocked with furniture, equipment, or personal belongings, reducing accessibility. Width and number of exit routes are often below the prescribed standards, making evacuation difficult in case of a fire. Lack of clear and illuminated exit signage further complicates evacuation efforts.

Overcrowding and Exceeding Occupancy Limits:

Several residential buildings exceed the permissible occupancy load as defined in the NBC. Overcrowding increases, the risk of congestion during evacuation, leading to higher casualty rates. Buildings with mixed-use (commercial and residential) increase the complexity of managing fire risks.

Lack of Fire Safety Training and Awareness:

Regular fire drills and emergency response training are not conducted in most residential complexes. Residents and staff lack knowledge about operating fire extinguishers, fire alarms, and evacuation procedures. Inadequate training leads to confusion and panic during fire emergencies.

Electrical Safety Violations:

Poor-quality electrical wiring, overloaded circuits, and lack of earthing are common issues. Short circuits and electrical malfunctions are among the leading causes of residential fires. Use of low-quality electrical materials and improper maintenance further increases the fire risk.

Poor Enforcement and Inspection:

Fire safety inspections by local authorities are

infrequent and inconsistent. Even when violations are identified, corrective actions are rarely enforced. Lack of strict penalties allows builders and property managers to overlook fire safety standards.

IV. CONCLUSION

Our analysis highlights that while India has a comprehensive legal framework for fire safety under the NBC and state-level fire codes, the actual implementation and enforcement of these regulations remain weak. The lack of proper fire safety infrastructure, poor maintenance of fire suppression systems, and insufficient training among residents and staff increase the risk of fire-related casualties. Overcrowding, blocked escape routes, and inadequate emergency signage further complicate evacuation efforts, raising the potential for injury and loss of life during fire incidents. To address these challenges, it is essential to strengthen enforcement mechanisms, increase the frequency and rigor of fire safety inspections, and impose stricter penalties for non-compliance. Building management authorities should ensure that fire suppression systems are properly installed, regularly tested, and well-maintained. Conducting regular fire drills and providing emergency response training to residents and staff will improve preparedness and reduce panic during actual emergencies.

Ensuring that residential buildings meet NBC standards and improving public awareness about fire safety will significantly enhance overall safety and reduce the likelihood of fire-related injuries and fatalities. A coordinated effort involving government agencies, building authorities, and residents is crucial to creating a safer living environment and minimizing the risks associated with fire hazards in residential buildings.

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