FIRE READINESS OF HIGH RISE COMMERCIAL BUILDINGS IN SRI LANKA

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SUPERVISOR’S DECLARATION

Under my supervision, the aforementioned candidate conducted research for his Master's thesis.

Name of the Supervisor: Chartered Quantity Surveyor Indunil Seneviratne

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Signature of the Supervisor Date

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ABSTRACT

Contemporary cities and enormous skyscrapers have been constructed due to the increasing population in urban areas. Evacuation strategies and the time needed to evacuate from the buildings are the main concerns of governments, construction developers and occupants. As a result, fire readiness is an important factor to consider when it comes to the safety of building occupants. There are a variety of people working in high-rise commercial buildings with varying thought patterns and educational levels. Furthermore, both active and passive safety systems have been installed at all high rise commercial buildings located within the city limits of Colombo, and without a satisfactory level of fire safety systems, the fire service department did not issue the fire clearance certificate for the high rise commercial buildings to operate. Aside from fire extinguishers, hose reel systems, fire alarm master panels, fire detectors, and sprinkler systems, active fire safety systems can be found in all high rise commercial buildings, while passive fire safety systems include emergency staircases, fire doors, and walls. Furthermore, an administrative team was appointed to administer and maintain the system installed in the buildings, and it is their primary responsibility to ensure the smooth operation of the high rise commercial buildings. In order to determine the fire readiness in 10 existing high-rise commercial buildings, questionnaires were given to tenants and management teams. Moreover, suggestions to improve the fire readiness appertain to buildings were identified using the same questionnaire. Total flooding and fire suppression systems do not appear to be a common fire prevention approach in the Sri Lankan context, based on the existing status of high-rise building fire preparation. Additionally, several standards that must be met, like familiarity with the buildings fire safety systems and knowledge of fire safety among the occupants, fall short of the required standard. Additionally, several construction criteria, such the accessibility of evacuation aids for individuals with disabilities and the plans for implementing fire training and awareness campaigns, fall short of expectations.

Keywords: *Fire readiness, Evacuation, High-rise, Buildings, Commercial, Sri Lanka.*

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AFP	Active Fire Protection
BCA	Building and Construction Authority
UK	United Kingdom
US	United State
VDU	Visual Display Unit

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CHAPTER 1 - INTRODUCTION

1.1 Background

The rapid urbanization of cities around the world has created large high-rise buildings and smart cities, so those metropolitan areas have a sizable population (Gershon, Qureshi, Rubin, & Raveis, 2007). As a consequence of this, building occupants, designers and governments have been given particular importance in the evacuation process during incidents (fire, terrorist acts, earthquakes and the tsunami) as many people live in the high-rise buildings. According to fire regulations (September 2017) in Sri Lanka, high-rise buildings have been defined as any building with more than ten floors including the ground floor, or whose height at any part of it above the ground level exceeds 30m,excluding a lift or motor-room not exceeding 56 m in extent or a staircase room not exceeding a height of 3m and not exceeding 25m in extent or a water tank not exceeding height of 1.5m(CIDA,2018).

Furthermore, Ma, Song, Tian, Lo, and Liao (2012) stated that modern cities with a lot of tall reinforced-concrete buildings owned by different people and occupied by different people are at a higher risk of being burned down in a fire. As a result, previous studies on fatal disasters show that inadequate building maintenance, building misuse, and poor building design are the primary causes of the emergence of life and property hazards in many disasters, particularly fires (Allman, 2006). As a result, it is critical to improve fire safety measures and to implement proper fire safety management systems in order to minimize the damage to occupants and property. Furthermore, those enhancements can be carried out with proper risk or hazard assessments of existing buildings (Drabek, 2001).

Because the large number of persons involved can endanger many lives with a single fire, greater attention has been paid to the process of evacuation of commercial buildings. (Ronchi & Nilsson, 2013)

The number of floors, evacuation strategy, and time required to evacuate people are the main factors to consider in an evacuation in a commercial high-rise building, which makes the process more difficult than in a normal building (Atila, Karas, Turan, & Rahman, 2013). The absence of the awareness about the proper behavior of residents during a fire evacuation in a commercial high-rise building is another major issue. (Aleksandrov, Rajabifard, Kalantari, & Tashakkori, 2015).

Furthermore, by providing real-time information to occupants during an evacuation of a commercial high-rise building, occupants will make accurate decisions (Shi, et al., 2009).

The "estimated evacuation time" is one of the most important pieces of concurrent information that residents should have access to (Bukowski, 2012). Adequate and appropriate fire readiness in buildings necessitates a complex process of analysis, synthesis, and evaluation. That is, identifying and analyzing potential risks and their consequences; synthesizing solutions by selecting the appropriate group of fire precautions to diminish the recognized risk to a satisfactory level; and the assessment of the selected group of fire precautions for practicability and acceptability, as well as the adequacy of the entire group of fire precautions (Aloi & Rogers, 2001). The primary goal of fire readiness provision is to achieve a level of fire safety that reduces the potential loss of assets and occupants to a manageable level.

1.2 Practical Problem

The lack of fire readiness systems in commercial high-rise buildings leads to many losses in the means of both lives and property (Kironji, 2014). As a result, it is critical to have fire readiness systems in place and properly maintain them in order to achieve the best results (Ronchi, Weng, & Jiang, 2011). In addition, an important problem remains an improper behavior of individuals in high-rise buildings during the evacuation process. Nonetheless, only a few studies have been carried out for Sri Lankan context to assess the fire readiness of occupants in high-rise commercial buildings. Furthermore, because nearly fifty high-rise building projects are underway in Sri Lanka, it is critical to investigate the fire readiness of those who will occupy high-rise buildings in Sri Lanka in order to improve fire readiness and ensure minimal damage in the event of a fire. Furthermore, any flaws in existing fire protection systems in buildings must be addressed immediately, and appropriate measures must be taken to correct the flaws. Moreover, it can be identified that, it is more crucial to evaluate the fire readiness of commercial buildings rather than domestic high-rise buildings as commercial buildings may deal with visitors rather than daily occupants of them. Hence, comparatively higher risk can be incorporate in these buildings. In case of a fire, visitors may get panic due to less knowledge of evacuation methods, directions and related systems. Therefore, it is essential in these commercial buildings to obtain ideal fire readiness to mitigate the damages caused by a fire. Despite there is a critical need in assessing fire readiness of these buildings, a gap can be observed in both literature and industrial implementation in Sri Lankan high-rise commercial buildings and providing recommendations to improve their fire readiness. As a result, the purpose of this study was to assess fire readiness and make recommendations to improve fire readiness of high-rise commercial buildings in Sri Lanka.

1.3 Aim and Objectives

The purpose of this research is to investigate the existing level of fire readiness of Sri Lankan high-rise buildings for commercial purposes and to make recommendations to improve it.

The objectives listed below will help to achieve the above aim,

1. To examine the current fire protection strategies used in high rise commercial buildings in Sri Lanka
2. To assess fire readiness in commercial high rise buildings in Sri Lanka
3. Determine the gaps in fire readiness of high rise commercial buildings in Sri Lanka
4. Suggest workable steps to increase the fire readiness of commercial high rise buildings in Sri Lanka

1.4 Research Methodology

The research was carried out using a mixed approach. The questionnaire was developed with the aid of the findings through literature review and the preliminary interviews. The findings through preliminary interviews of tenants and management teams which were primarily focused on emergency evacuation strategies and fire safety initiatives were thoroughly analyzed qualitatively in manual method in order to validate literature findings and re-structure the questionnaire for the data collection purpose. In the data collection phase through questionnaire survey, quantitative method was used to analyzed gathered data from the professionals, those who are working as Fire Wardens, Fire Marshals, Managers, Team Leaders, Floor in Charges, and Heads of Fire Departments in commercial high rise buildings were involved in this study. A set of structured questionnaires were distributed to officials at ten high-rise commercial buildings, and completed questionnaires were collected. The data analysis was carried out using statistical analysis pertaining to the collected hundred questionnaire responses.

1.5 Scope and Limitations

This study was limited to high-rise commercial buildings within the Colombo city limits. Aside from that, these high-rise commercial buildings were chosen at random, so their levels of fire readiness vary greatly from one to the next.

Additionally, administration personnel from high-rise commercial buildings such as fire marshals, property managers, team leaders, floor in charge, facility managers, and department heads were included in the study. Furthermore, the perspective of building residents were discussed in support of fire readiness concerns as data collecting from laymen people like janitors and other employees were not practical in such a specialized domain.

1.6 Chapter Breakdown

Chapter 01- In this chapter, the study describes the background for the research and includes the research's aim, objectives, research methodology, and scope.

Chapter 02 - For this chapter, the literature survey includes previously published research papers, journals, articles, books, reports, and electronic media concerning fire readiness of occupants in high rise commercial buildings.

Chapter 03 - The third chapter depicts the research methodology and analytical method used in the research study. This chapter describes how the project was carried out, the activities carried out during the project, the manner in which the project was carried out, and the method of data collection and analysis.

Chapter 04 - The fourth chapter presented the data analysis and discussed the results and findings of the research study.

Chapter 05 - The conclusions and recommendations in Chapter 5 were derived from the results of the data analysis.

CHAPTER 2 - LITERATURE SYNTHESIS

2.1 Introduction

The preparedness of occupants in the case of a fire emergency is a continuously evolving knowledge area. The design of new buildings, their contents, and the materials used pose ever-changing challenges to designers and manufacturers of automatic fire detection equipment and fixed extinguishing installations, as well as to fire prevention officers. Warehouses, shopping malls, atria, condominiums, and hospitals all necessitate very different approaches and solutions.

Large high-rise buildings have become increasingly popular in modern cities as living conditions have become much more convenient as architectural technology has advanced; however, this has introduced new fire hazards (Ye, Ma, Shen and Lin, 2015). The authors also said that the flammable goods within the buildings form a single type of fuel distribution because most goods are stored centrally for easy classification and transport due to their usually large interior space.

Fire protection procedures were documented since the initial ancient period of the Qing Dynasty (1644 - 1911 AD), and they can be divided into three classifications: symbolic features, building construction, and urban planning (W.Y Cheng, Lo, Fang and Cheng, 2004). In 2014, a total of 395,000 fire cases were reported, resulting in 1817 deaths and a direct owned loss of 4.39 billion Yuan, according to the Chinese Fire inventory. The fire in a large space building has gotten a lot of attention lately (Ye et. al., 2015).

More than 480,000 building fires were extinguished by fire departments in the United States in 2013 (Evarts & Stein, 2020). These fires resulted in approximately 2850 civilian deaths, 14,000 injuries, and $10 billion in property losses. (Anthony P. Hamins, Casey Grant, Nelson P. Bryner, Albert W. Jones, and Galen H. Koepke, 2015).

Every year, fires in the United Kingdom kill approximately 800 people and injured 15,000 others (U.S Fire Administration, 2019). The direct material damage was approximately £1,200 million per year on average, and the indirect loss was approximately £120 million (U.S Fire Administration, 2019). In Sri Lanka approximately 900 people affected from building fire related cases annually (Disaster Management Centre, 2007)

2.2 Categories of buildings

- **According to the height**

A “tall building” can be described as a multi-story structure where most occupants ensure reaching their destinations by elevators. Most countries referred to the tallest structures as "high-rise buildings," where "tower blocks" is the term that Britain and European countries referred to these gigantic structures (Dennis Challinger , 2008)

Buildings over 15 floors and a height of 45 meters, including the ground floor, are called super high-rise buildings while buildings over 10 floors, including the ground floor, are known as high-rise buildings above a height of 30 meters (Craighead, 2009). In addition, buildings with less than 10 floors, including the ground floor and more than 18 meters high, are referred to as medium-rise buildings and low-rise buildings, with a maximum elevation of less than 18 meters. (ICTAD /SCA/9,2014).

- **According to the construction type (Based on materials)**

Buildings are classified into five types based on their construction (Types 1–5), namely Fire-Resistive, Non-Combustible, Ordinary, Heavy Timber, and Wood-Framed, ranging from the strongest to the most likely to fail quickly in the event of a fire (Randy Frassetto , 2012).

2.3 Fire Readiness and available Fire Protection systems in high rise buildings

More visible features in building design were included as people learned more about fire and gained experience in construction, and they realized that fire was simply a natural phenomenon that could be avoided (W.Y Cheng et. al., 2004).

In the narrowest sense, fire readiness refers to precautionary measures taken to prevent fires from igniting. However, in books, articles, and other materials on the subject, fire prevention frequently encompasses the broader terms of fire protection, fire safety, and fire science, which are drawn from various branches of the sciences and management and deal with the behavior, effects, and control of fire (William Wiese, 1986). In many high-rise buildings, different evacuation strategies can be identified. Total evacuation, phasing out, defensive and delayed evacuation are the most common strategies currently used. (E. Ronchi and D. Nilsson, 2013).

In these buildings, there is a significant probability to fire occurrence. There is, however, no focus on the evacuation of high-rise buildings. In this way the influencing factors of high-rise building evacuation need to be analyzed and a set of high-rise building development assessment methods based on high-level building characteristics. (Yongxing Tong , Zhen Zhou , Yongqing Jiang, Dezhong Ma, 2014)

The contribution of various fire protection systems is usually compared in a performance-based design evaluation. Fire protection systems accomplish a specific goal, as they were intended to do. Fire protection systems are classified into two types: passive systems and active systems (ICTAD/SCA/9, 2014). Fire barriers by rating and opening protection of fire barriers can be referred to as passive systems, whereas fire detectors and sprinklers are active systems. (James A. Milke, 2014).

2.4 Active systems

A method of assisting in the prevention of fire-related loss of life and property by extinguishing, suppressing, or controlling a fire through functional systems. Active fire protection includes sprinkler systems, fire alarm systems, and smoke detection systems (Hamins A.P et.al.,2015) Active systems are all electromechanical systems that must be installed in order to provide fire detection and protection (ICTAD/SCA/9,2014).

Active fire protection (AFP) is an integral part of fire protection. AFP is characterized by items and/or systems, which require a certain amount of motion and response in order to work, contrary to passive fire protection. Manual actions can be observed such as a fire extinguisher, or automatic, such as a sprinkler, but they all require certain amount of action. Additionally, AFP includes fire/smoke alarm systems, sprinkler systems, fire extinguishers, and fire fighters to assist in the total extinguishment of the fire (Evans, 2005).

2.4.1 Sprinkler systems

Sprinkler component has been recognized as highly efficient, reliable component of a building-based fire protection system, and national fire reports from the National Fire Incident Reporting System (NFIRS) of the U.S. and Fire Administration (NFIRS), as well as NFPA's annual fire department survey demonstrate that 10 per cent of US fires reported in buildings where sprinklers had been installed from 2010 to 2014.

Moreover, death rates per 1,000 fires reported where sprinklers were incorporated, 87% lower than for properties without the AES and civilian injuries were 27% lower, and firefighters' firefighting injuries per 1,000 fires were 67% lower for sprinklers than for properties without the ASE in a case of fire. (Marty Ahrens, 2017).

Sprinklers which actuate automatically are highly efficient components of total fire protection system designs. It saves lives and property, leading to considerable reduction in the number of fire deaths, an average direct damage to property per fire and, most importantly, a significant loss of life or property resulting from a fire (Hall, 2011).

Fire sprinklers can sprinkle a fire while burning it still. A projected average of 49,840 (10%) reported building fires was found to be sprinkling in certain types between 2010 and 2014. Fires are to be controlled until flames arrive in the automatic extinguishing systems (AES). Sprinklers in a fire protection system in a building can be further recognized as AES that use water to put out fires. Other forms of AES are used which not use water to. (Ahrens, 2017).

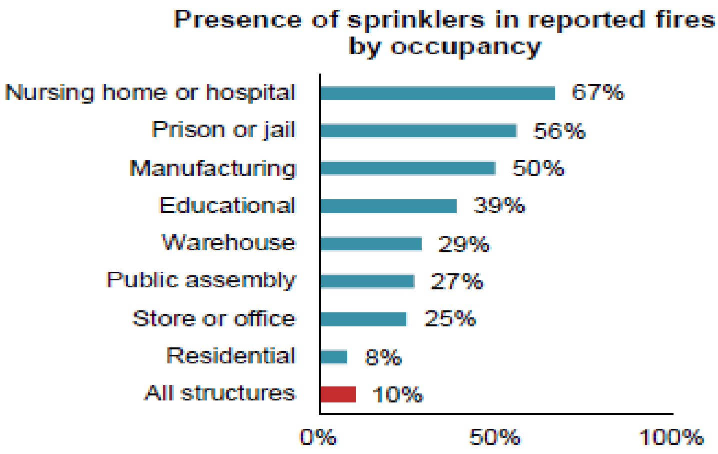


Figure 2.1: Existence of sprinklers in reported fires by occupancy

(Source: US experience with sprinklers, National Fire Protection Association report, 2017)

The significant reduction in death with a wide range of industries and occupations in the United States, as well as the fire death in warehouses, should not be used as justification to eliminate warehouse sprinklers, and the reasons why sprinklers are ineffective are shown in tables 2.1 and 2.2. (Hall, 2011).

Table 2:1: Fire Death Rates with and Without Sprinklers

(Source : US experience with sprinklers ,National Fire Protection Association report ,2017)

Occupancy	Fire death rate* without auto extinguishing system	Fire death rate* with wet pipe sprinkler	Percent reduction
All public assembly	0.4	0.0	100%
Residential	7.4	1.2	84%
Store/Office	1.2	0.2	81%
Manufacturing	1.8	0.3	84%
Warehouse	1.2	2.0	-67%
Total	6.2	0.9	85%

Table 2:2:Reasons for Sprinkler Ineffectiveness

(Source : US experience with sprinklers ,National Fire Protection Association report ,2017)

Reasons for failure	All	wet pipe	Dry pipe
System shut off	65%	61%	74%
Manual intervention defeated system	16%	19%	8%
Lack of maintenance	7%	8%	4%
System component damaged	7%	6%	10%
Inappropriate system for type of fire	5%	6%	3%
Total fires per year	738	564	130

The most common reason given for failure of the sprinkler is that the system has been disabled prior to starting fire, which can occur during routine inspection and maintenance processes (65 percent failure). Other leading causes were manual operation which failed (16%), maintenance deficiency (7%) and an inappropriate fire type system (5 percent). Only 7% of the sprinkler failures caused component damage (Hall, 2011).

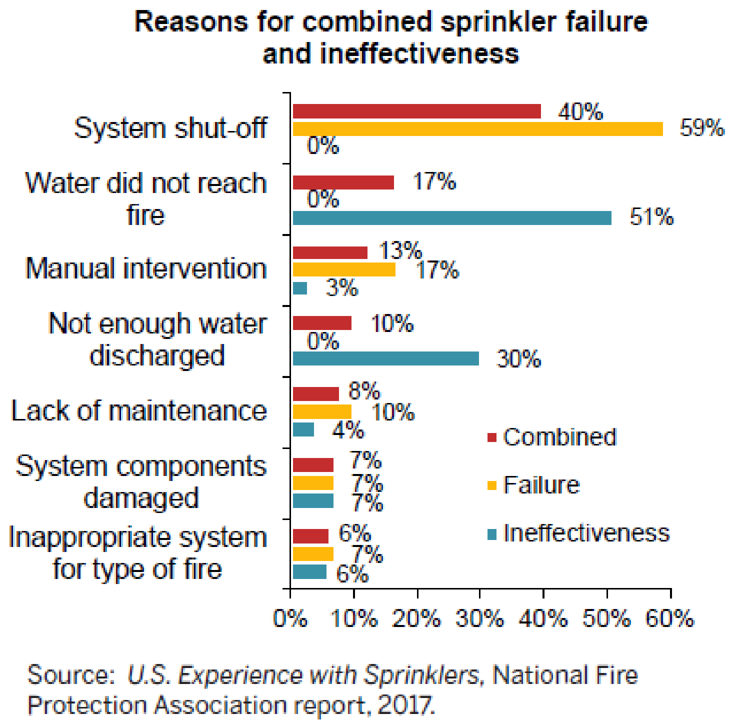


Figure 2.2: Reasons for combined sprinkler failure and ineffectiveness

2.4.2 Fire Alarm Systems

Fire alarm systems, like all other electronic equipment, are rapidly and continuously evolving. In this sense, categorizing one system as new generation and another as not is incorrect (Todd & Tong, 1986).

A variety of fire alarm system devices work together to detect and warn people of a fire. This can be done through visual or audio devices, especially when there is a fire, smoke, or carbon monoxide present, as well as other emergencies (Hall, 2011).

Traditionally, fire alarm systems produce two types of information: sounders to warn building occupants to evacuate and visual information on indicator panels of annunciators in key locations such as a security center or a porters' lodge to initiate the emergency response. Traditional annunciators only provide an indication of the zone where a detector has operated, whereas new generation systems provide options for improvement in both of these areas. Furthermore, new generation systems are frequently linked with Visual Display Units (VDUs) that can display a variety of data (Todd & Tong, 1986).

In a study conducted between 2013 and 2016 of fire incident in the United States, fatal rates of causation in homes without operational smoke detectors were 1.10 fire fatalities compared to 0.52 fire fatalities in the operational smoke detectors. There has been a more than 50% decrease. (James et al., 2010)

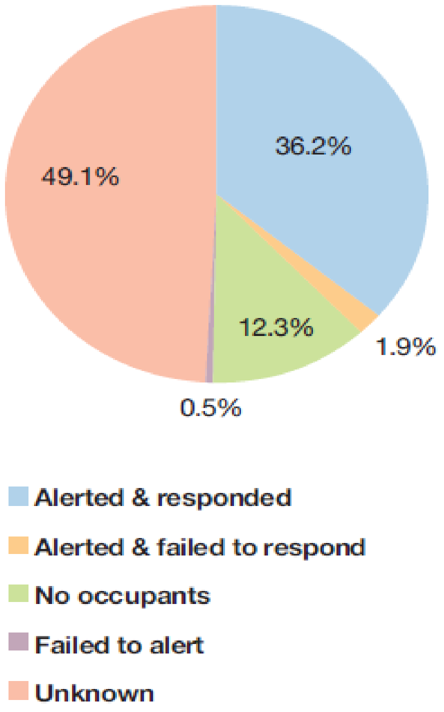


Figure 2.3: Operation of smoke detectors in US fire incidents

(Source : US experience with sprinklers ,National Fire Protection Association report ,2017)

In Sri Lankan fire regulations, there is a general guidance in selecting fire alarm system. The requirement of a fire alarm system for a particular building and the system should conform to the given regulations. (ICTAD/DEV/14, 2006). Figure 2.3 illustrates individuals responding in US fire incidents to the operation of smoke detectors, especially in trade occupations (Milke et.al, 2010).

2.4.3 Fire Extinguishers

Portable fire extinguishers that can be observed in accordance with Sri Lankan standards were effective against the type of fire that covered the nature of the processes or contents within a building. It must be provided and kept fully charged and operational as required by the Urban Development Authority (ICTAD/DEV/14, 2006). Figure 2.5 depicts how fire extinguishers must conform to the relevant

provision of the British Standard - BS EN 3 and be color coded or banded according to their type (ICTAD/SCA/9,2014). There are three factors required to support combustion, which can be depicted as a fire triangle. These elements are fuel, oxygen, and heat, and removing one or more of them will extinguish the fire (NEBOSH International General Certificate Vol.2 - TWI Gulf WLL ,2009).

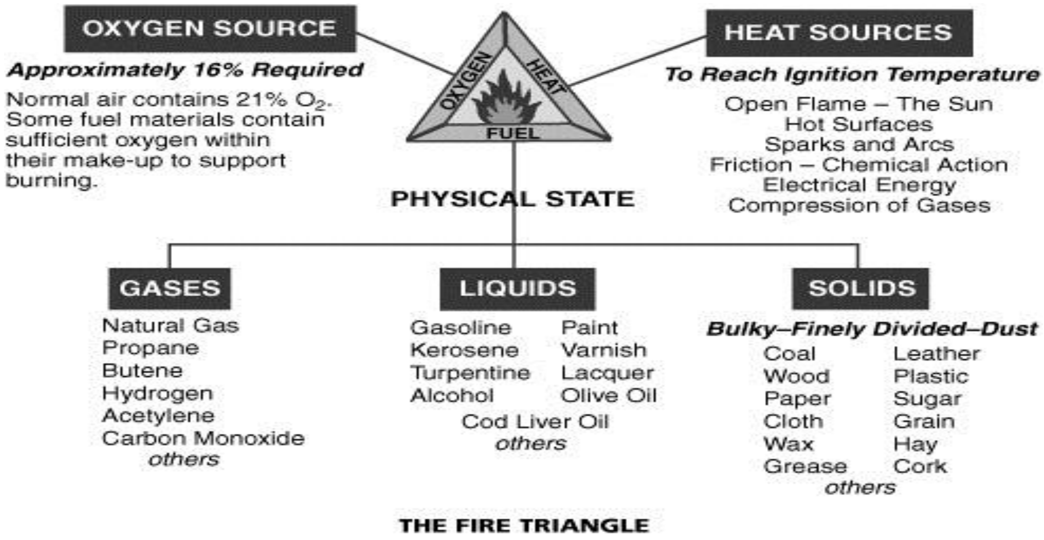
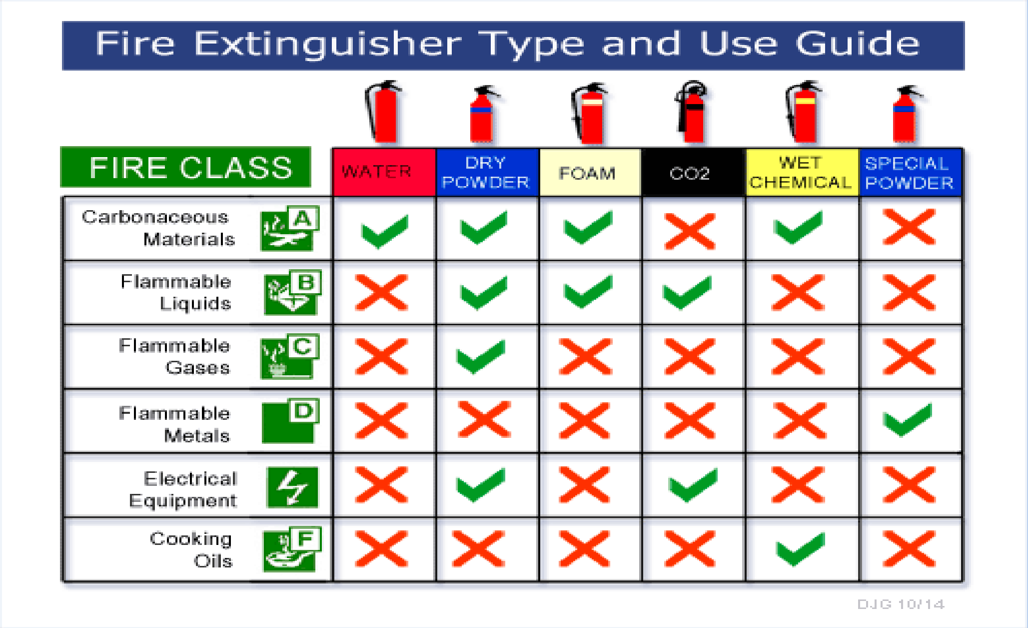


Figure 2.4: The Fire Triangle - Institute of Fire Engineers hand book ,U.K

Fire Extinguisher Type and Use Guide



FIRE CLASS	WATER	DRY POWDER	FOAM	CO2	WET CHEMICAL	SPECIAL POWDER
Carbonaceous Materials (A)	✓	✓	✓	✗	✓	✗
Flammable Liquids (B)	✗	✓	✓	✓	✗	✗
Flammable Gases (C)	✗	✓	✗	✗	✗	✗
Flammable Metals (D)	✗	✗	✗	✗	✗	✓
Electrical Equipment	✗	✓	✗	✓	✗	✗
Cooking Oils (F)	✗	✗	✗	✗	✓	✗

DJG 10/14

Figure 2.5: BS EN 3 color - coded Fire Extinguishers

2.4.4 Hose Reel system

A metal reel permanently connected to the water supply on which is wound rubber tubing with a diameter of 19mm or 25mm. The minimum requirement of having at least one hydraulic hose reel shall be provided in every story of every building except one that does not exceed a maximum height of 18 M, a shop on the ground story of a shop-cum-residential building provided the shop does not exceed 280m2 in floor area, and any other building. (ICTAD/DEV/14, 2006).

Front and side elevation of a hose reel system is shown in figure 2.5 according to the BS 5247-14(1975) :1975 standard.

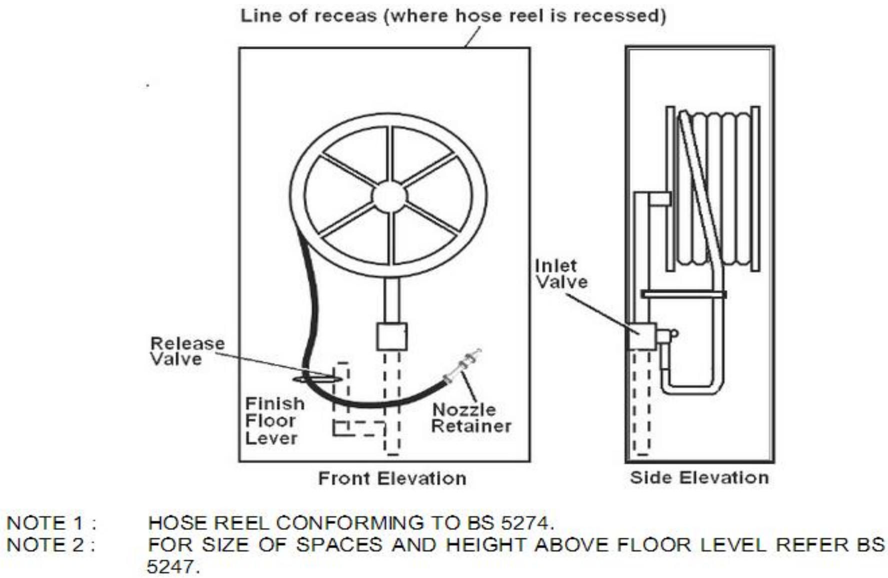


Figure 2.6: Front and side elevation of a hose reel system according to BS 5247-14(1975) :1975

2.4.5 Total Flooding System

These are automatic systems that can protect against most types of fires, but they are most commonly used to protect electrical control rooms and computer rooms. A high concentration of an extinguishing gas, usually carbon dioxide, is flooded into a specific enclosed area automatically (NEBOSH International General Certificate Vol.2 - TWI Gulf WLL ,2009).

The total flooding system must meet seven requirements: environmental friendliness, no or low toxicity to humans, ozone depletion potential of the agent, global warming potential of the agent, atmospheric life time, application rate, and adequate warning to allow any person in the enclosure to evacuate before the agent is discharged (ICTAD/DEV/14,2006).

2.5 Passive system

Passive fire protection is a group of systems that use fire resistance to compartmentalize a building, and this fire resistance is related to both the wall and the floor, preventing the fire from spreading quickly. Furthermore, the process will give people trapped inside the building time to flee. Dampers are useful in facilities (Rosenbaum, 1996).

The passive system refers to the measures to be taken for structural fire protection and escape routes. (Definitions: ICTAD/SCA/9, 2014) In buildings that are resistant to fire, more than 81 percent of fires include the room or floor of origin. There is an increase of more than 18% over the base case, which consists of a building with a protective system. In a more extreme case, the fire can be contained to the room or the floor (Hall, 2011).

Passive protection can be accomplished basically by the fire resistance. fire resistance has been defined element of structure door or other part of a building shall have fire resistance of a specified period shall be construed as meaning that it shall be so constructed that a specimen constructed to the same specification, if exposed to test by fire in accordance with as 476, would (subject to any relevant provisions in the Table to this Regulation) satisfy the requirements of that test as to stability, and insulation for not less than the specified period (ICTAD/DEV/14,2006).

2.5.1 Fire Doors and Walls

Swinging Type Fire Doors, Fire Door Frame, Hardware, Hinges, Hardware, Locks and Latches, Astragal, Wall Assembly are all highlighted on the UL Fire Resistance Directory. As shown in table 2.3, the hourly rating of the door assembly is determined by the design and fire rating of the wall assembly (GSNN.SP-2-003 ,2011)

Table 2.3 :Design and fire rating of the wall assembly

(Source : "GSNN.SP-2-003 - Fire Door Assemblies and Window Assemblies". Database.ul.com. 2011-04-22. Retrieved 2013-05-17)

Maximum Fire Rating of Door Assembly, Hr	Wall Design	Fire Rating of Wall Assembly, Hr
3	V460	4
1 -1/2	V466	2

In general, indicates that the structure is capable of resisting flame and smoke passage and providing insulation in accordance with current British Standard 476. Furthermore, FD30 doors should not be less than 44 mm thick; FD60 doors should not be less than 54 mm thick; and door widths and means of escape are shown in table 2.4. (Fire doors - General specifications and over view, 2016)

Table 2:4: Door widths and means of escape

(Source : "Can You Count on Your Fire Doors?" Record, Factory Mutual Research Corporation, July/August, 1991)

The following guide can be used to determine the general capacities of escape routes based on clear opening door widths:	
Door Widths:	**Numbers of persons able to pass through:**
750 mm (absolute minimum width)	**60 persons** (normal risk)
850 mm	**110 persons** (normal risk)
950 mm (minimum width for wheelchairs)	**160 persons** (normal risk)
1050 mm	**220 persons** (normal risk)
Doors greater than 1050 mm wide	**1050mm = 220** persons then Add 5mm per person on width greater than 1050mm (e.g. door width of 1500mm - 1050mm = 450mm (450 ÷ 5mm = **90**) 220 + 90 = **max 310 persons**

- An additional 75mm should be allowed for each additional 15 persons (or part thereof 15);

FM Global was one of the companies that examined 1600 fire door installations. The survey included several types of fire doors, including rolling steel, horizontal sliding on inclined tracks, counterweight or spring closures, vertical sliding, and swinging doors. Due to the lowest reliability of rolling steel doors of 80% and highest reliability of 93% for vertical sliding doors, 82% of these doors worked properly (James A. Milke, 2014). In a survey of 91,909 fire doors installed in various occupancies, 12,349 (13.4 percent) doors had been opened (Dusing, Buchanan and Elms, 1979).

2.5.2 Fire Dampers

Passive fire protection devices in the heating, ventilation and air conditioning ducts are fire dampers. In a fire resistance rating, smoke dampers are extremely similar to fire dampers and therefore, particularly within the conduct through fire resistance rated walls and floors. Furthermore, it will prevent the spread of smoke within the ducts, and when the temperature rises, the fire damper tends to close. (2016, Fire Doors - General Specifications and Overview) The evaluation of a fire damper to prevent the spread of fire and hot gases from one compartment to another, as well as the size of the dampers to be tested in accordance with ISO criteria(ISO 10294-1 ,1996)

2.5.3 Penetration Seals

Effective fire-resistance in fires The use of fire-resistant separating elements is critical in containing a fire at its source, thereby reducing its impact on the primary building structure, and the degree of spread is controlled by dividing the building into fire-resistant compartments (ASFP ,2004)

There are numerous other techniques that would reduce the impact of a fire on the fabric of the building, and these must be amalgamated into the design of the building from its compartments in order to close off to stop the spread of fire. Confining a fire to a specific point is considered a key goal of any safety measure, and compartmentalization with fire separating elements that confine a fire to a specific area is considered a key goal of any safety measure (ASTM E814,2013).

All openings in fire zone walls and floor slabs caused by the installation of electrical and mechanical services or other means must be sealed with intumescent material to prevent the spread of smoke and fire (ICTAD/SCA/9,2014).

2.5.4 The emergency staircase

Any internal staircase (including any hall or landing associated with it and any part of a floor which affords passage between flights of the staircase) in any building with more than three stories must be separated from all other parts of the building by structure that is fire resistant for at least half an hour for elements of structure forming part of the story in which it is located (ICTAD/DEV/14 ,2006).

2.5.5 Staircase pressurized fan

Any duct work associated with a pressurization system must be made of galvanized sheet steel and designed, fabricated, and installed in accordance with the relevant ASHRAE standard or an approved equivalent. As a result, it must maintain a minimum ambient pressure of 50 Pa in the protected area, while fan motor insulation must be class F and protection class must be IP 54 or higher (ICTAD/SCA/9, 2014).

2.5.6 Surfaces of walls and ceilings

Fire propagation index, which provides a comparative measure of an essentially flat material, composite, or assembly's contribution to fire growth. Its primary purpose is to evaluate the performance of internal wall and ceiling linings (BS 476: part 6, 1989)

2.6. Fire readiness of occupants

Fire Readiness establishes standards, procedures, and requirements for the orderly evacuation of occupants from any high-rise building, including fire-related evacuations (NFPA 2014 - Guidelines to Developing Emergency Action Plans for All-Hazard Emergencies in High-Rise Buildings). Factors that affect high-rise building evacuation must be analyzed and a series of high-rise building capacity assessment methods should be proposed based on high-rise building properties (Yongxing et. al., 2014).

The procedures to be followed in case of a fire or other urgency should be directed annually to all building occupants and they should take part in compulsory drills. The instructions for occupants should be documented and all new occupants should be given these instructions within 14 days from occupancy. (NFPA 2014 - Guidelines to Developing Emergency Action Plans for All- Hazard Emergencies in High-Rise Buildings) Previous studies only tested different evacuation strategies in tall high-rise buildings, with the overall conclusion that occupants should be encouraged to use elevators rather than overcrowded stairs. However, there is no method to encourage occupants to use evacuation elevators instead of stairs (R. W. Bukowski, 2012)

Aside from fire events, high-consequence crises have been described as arising from safety issues such as improper use of electrical equipment, smoking, or a lack of attention to safety regulations and work procedures (Lizhong, Y., Xiaodong, Z., Zhihua, D., Weicheng, F., and Qing'an, W, 2002). However, due to the robust construction and redundant fire safety features of high-rise structures, emergencies rarely necessitate a full-scale evacuation (Robyn R.M. Gershon, Kristine A. Qureshi, Marcie S. Rubin, Victoria H. Raveis , 2006)As discussed above it is obvious that, occupant's behavior is way critical to minimize the damage in case of a fire as much as the building's fire readiness. Despite all the proper functioning system in a case of fire the wrong acts and negligence of an occupant can cause a tragic situation. Therefore, the high focus on occupant's behavior has been dragged all over the world to mitigate damages in case of a fire. In the Figure 2.7, the World Trade Centre evacuation study overview has been illustrated. In there also higher focus has been given to participant's actions and behavior in the evacuation process.

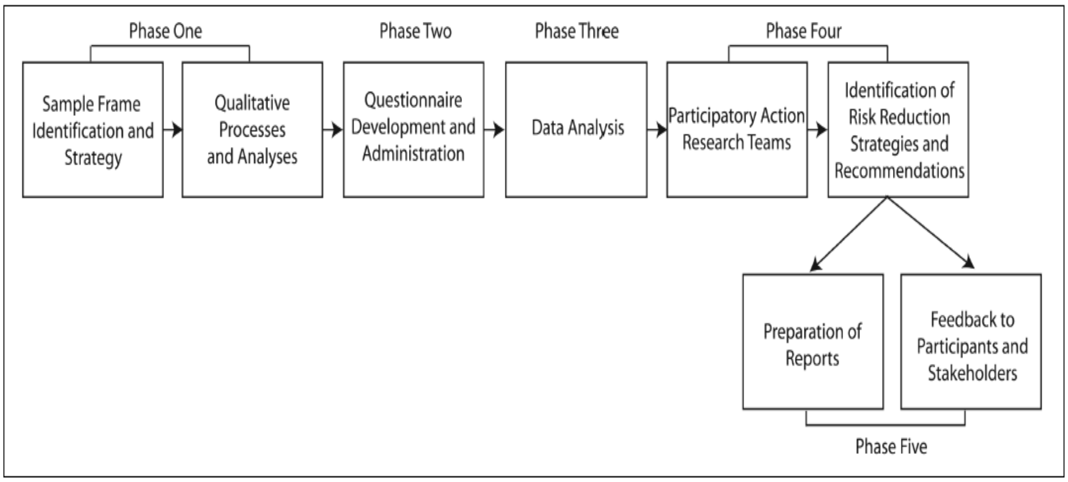


Figure 2.7 : World Trade Center Evacuation Study overview

(Source : Gershon © 2007 Prehospital and Disaster Medicine)

2.6.1 Beliefs and attitudes of the occupants

A person's attitude towards the safety and regulations has a direct impact on his fire readiness. In order to prepare himself for a sudden incident like fire, he should have to obey all the safety and regulations of the building without any reluctance. Include himself in mock fire drills in regular basis and participate to each safety program carried out by the fire officials of the building can be very favorable to protect himself and others as well in case of a fire. In a commercial high rise building there may be number of strangers who are not considered as regular or permanent occupants of the building and they are entering and exiting premises deliberately. In this situation, it is impractical to involve them for simulated drills or fire evacuation training programs when those events are taking place.

If at all feasible, we must take whatever action we can to involve them in such an occasion. Permanent inhabitants, however, have a huge responsibility to become fire prepared and urge other renters, especially those strangers who aren't thought to be there frequently or permanently, to evacuate safely.

2.7 Actions to improve fire readiness of occupants

Fire safety management should put together a fire drill schedule. Maintenance and control of firefighting equipment should be a priority. Fire safety programs should help to improve fire safety measures and fire preparedness in the community. It is necessary to undertake more research on the difficulties experienced during evacuation based on human behavior, as well as on the construction and specification of fire resistant structures (Mishra & Shrestha, 2017). The eight-item scale evaluated essential aspects of building management and employer emergency preparation as mandated by OSHA. An evaluation of the designation of an individual responsible for ensuring that everyone evacuated, the provision of written fire safety and evacuation information, post-evacuation designation meeting places and plans for conducting a head count, the designation of a person in charge of fire drills, and management and coworker participation in fire drills were among the items (Glauberman, 2018).

According to the Federal Emergency Management Agency (FEMA), basic disaster preparedness strategies include gathering information about hazards and emergencies affecting families in a specific location, developing an emergency plan, assembling a disaster supply kit, learning where to seek shelter from all types of disasters, identifying warning systems and evacuation routes, and practicing and maintaining an emergency plan (Glauberman G, 2018). This has been accomplished in a more understandable manner by developing emergency escape procedures, emergency escape route assignments, and emergency escape procedures for employees who remain on site after the alarm sounds (Ball, 2001).

The First Interstate Bank fire in Los Angeles in 1998, the Parque Central Tower fire in Caracas in 2004, and The Mandarin Oriental Hotel fire in Beijing in 2009 are three examples of high rise buildings where structural fires developed and involved several floors and in both the First Interstate Bank and Parque Central Tower, active fire safety systems had been foreseen in the buildings, despite not enforced by the regulations at the time; however sprinklers did not activate, due to faulty maintenance or impaired installation, and the fires spread upwards involving a number of floors and lasting several hours (Gentili , Luisa and Bontempi,2013) .

There is an immense failure in maintaining a building's fire protection system as well as the associated system and the equipment that has been used. Thus the responsibility has been passed to the facility manager to spend time putting out fires or fixing an air-condition that is not working or it may be the hot water that is not available. But the most significant item for any facility manager is the maintenance of safety for the people that live and work in the building. This would require extensive knowledge that covers the fire protection system while considering operations that have been tested as frequently as possible. He is expected to have a good understanding of how sprinklers as well as fire alarms work. Non-operation of these items can cause a catastrophe. The element of risk, a duty of care and the prime responsibilities of the fire and the safety of the lives that occupy the building is a major burden on the facility manager (Chow ,2001).

One of the gravest needs is to provide an adequate level of fire safety of buildings as well as other structure taking to consideration the need to be given a whole range of connected design and aspects. Prevention has become an important component that depends on the safe installation and use of heat producing and energy consuming devices. These devices safely conduct operations that can be involving hazards of ignition. Importance of fire prevention is concerned with human responsibilities to ensure that accidental fires do not start. Training and education is needed at all levels as it plays great importance in ensuring that the people living in the building are safe. Here people must be made aware of the risk involved if a fire does break out. If a fire does occur it is very important that the occupants are made aware that they have to move to places of safety. This requires knowledge of safety and provisions which have been made to ease the identification of the route that needs to be followed. In the case the building is large and complex, it is important to increase the safety within the building. It is not normally expected that the occupants would use on site facilities to control the fire. They may be able to control or tackle the fire with the use of a fire extinguishers but big fires they are advised to inform the fire brigade. Un-aided evacuation of occupants may be difficult and thus provisions may need to be made with rescue services to give assistance (SekizawaFbihara,Notake 2003)

The high-rise office building drew the most attention. The investigator's primary objective was to "examine how emergency provisions may be built if the designer proceeded logically from clearly stated premises or principles through to design conclusions...," Applying this principle to the design of emergency provisions requires the designer to clarify the behavioral goals related to the occupancy and building features." To forecast whether a setting would fulfill the behavioral goals, he would also require theoretical knowledge of some type of testing (Arthur Cohen, 1974).

Since the 9/11 terrorist incident, homeland security efforts and the readiness of local emergency management agencies have become focal points in the war on terrorism. A significant issue faced by front line responders has been the significant increase in the number and type of potential incidents they must be prepared to handle.

We describe a simulation-based approach that allows local county-level emergency management agencies to more quickly develop, test, and refine robust plans for an ever increasing list of potential threats. The focus of the simulation environment is on the information flow, coordination, and response of medical, police, and fire resources (Proceedings of the 2003 Winter Simulation Conference, New Orleans, LA, USA, 2003).

In addition to safety of occupants within the building where the fire occurs, the people living in an adjacent building also become important. There may be instances where the adjacent building is attached to the building that is on fire. This is a very dangerous situation. If the buildings are wide apart then the chances of another building catching fire will be low .This consideration is important because of the risk that is created when high rise buildings are involved in such a fire. It is thus very important that all buildings be maintained. The facility managers need to keep up the high standards in relation to the safety of the buildings.(American, 2008).

2.8 Chapter Summary

Literature review was carried out in this chapter to examine the current fire protection strategies used in high-rise commercial buildings. It was highlighted that several requirements related to active fire protection system such as sprinkler system, fire alarm system, fire extinguishers, hydraulic hose reel system, total flooding system, fire hydrants, fire suppression systems, etc and passive fire protection system such as fire doors and walls, fire dampers, penetration seals, emergency staircases , etc. Additional elements that determine how fire-resistant high-rise buildings are include the need for an alternative, protected stairway that is at least one meter wide and accessible from all floors (CMC, 2017). Further scissor type protected stairways are not acceptable as alternative means of escape for super-high rise buildings. Additionally the dimensions of the evacuation lift 2100mm x 1100mm for the evacuation process and firefighting shaft must be taken in to account.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1 Introduction

In Chapters 01 and 02, a literature review was conducted, as well as the identification of the research problem. The aim of this chapter is to describe how the research aim and objectives have been accomplished. Thus, this chapter therefore explains as the research methodology.

3.2 Study Setting

The purpose of this study was to investigate the fire readiness of occupants in high-rise commercial buildings in Sri Lanka. This segment represents a reasonable amount of information pertaining to fire readiness, fire protection systems, and emergency evacuation pertaining to fire safety obtained from the selected commercial high-rise buildings over a five-year period from 2013 to 2017.

3.3 Sample of the Study Population

The criteria for choosing a case are based on convenience, judgment, time and cost constraints (yin , 2011). Additionally, probability sampling gives every item in the population an equal chance to be included in the sample by random selection, but non-probability sampling allows the researcher to purposefully choose items for the sample (Kothari, 2004). It was used the random sampling method for this study since this study look into the fire readiness, so that preparation has to be in the all the occupants even in case if it has been selected randomly. The study's intended sample size was 100 participants from a total of 130 who were serving as Fire Wardens(1), Fire Marshals(1), Managers(3), Team Leaders(2), Floor in Charges(2), and Heads of Departments(4), representing tenants and the administrative team. Because there was limited data access random sampling was used to gather data from ten high-rise commercial buildings and 13 respondents were chosen from each building. As a result, a total of 130 (13x 10) respondents were chosen and 100 of those respondents provided responses.

3.4 Study Design

The idea of this study was to collect information concerning fire readiness in high-rise buildings over five years. This research design expresses preliminary study, literature synthesis, questionnaire survey and analysis of the collected data using

3.5 Data collection tools

- Preliminary Survey to create a platform for questionnaire survey
- Reference of past evacuation drill reports
- Reference of past fire incidents
- Questionnaire Survey

3.6 Research Process

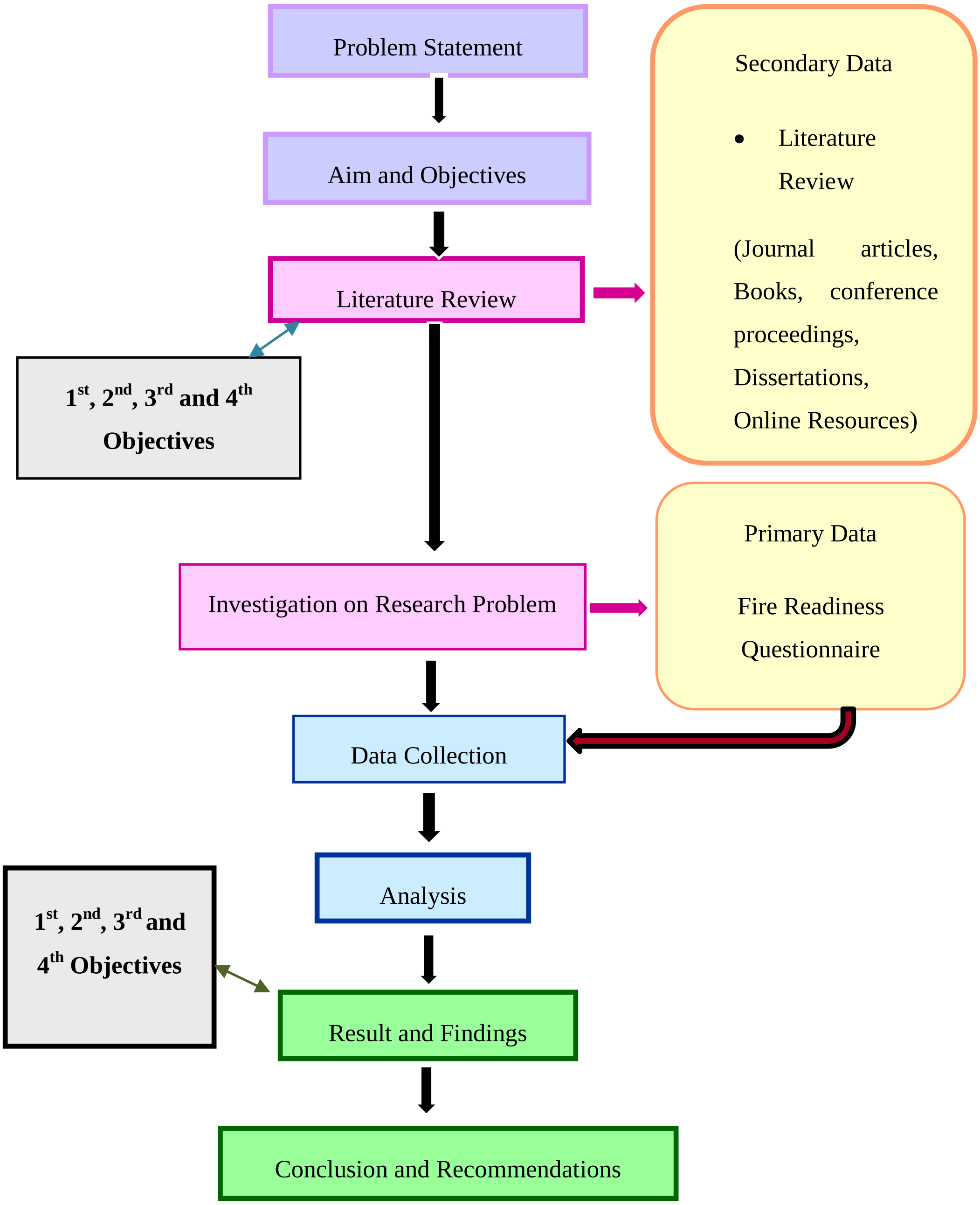


Figure 3.1: Research methodology

3.7 Data Collection

Interviews, questionnaires, document surveys, participation, and observations are typical data collection techniques (Tan , 2002). The primary method for gathering data for this study was a preliminary survey based on the results of the literature, followed by a questionnaire survey. Secondary data was acquired using records from prior evacuation drills and fire incident reports that had been stored with the buildings for a period of time. Tenants and representatives of the building administration affiliate with 10 high rise buildings that were chosen participated in the preliminary survey. It was anticipated that the preliminary survey would validate and modify the literature findings in light of the Sri Lankan context.

3.8 Sampling Techniques

A sample is a representative sampling of the whole population of a population. Researchers must gather data from the general population; when the general population is too large, a sample of the general population is selected for data collection; this sample can be selected either non-randomly or randomly, depending on the research question. It was decided on the sample size in this investigation by employing the Snowball sampling approach. This approach was a simple and quick way to choose a representative sample from a large group of people.

3.9 Questionnaire Survey Data Analysis

Data analysis is an important activity in the research process because it allows the data to be processed using the most relevant information collecting approaches to produce the intended findings. It was able to obtain a platform for a questionnaire survey based on the findings of the preliminary investigation. Individual factors, occupant awareness, and building requirements related to fire readiness of high-rise buildings were verified and used in the questionnaire survey in accordance with the preliminary study. The survey contained open-ended, closed-ended, and multiple-choice questions using a 5-point Likert scale. Cronbach Alpha was used to assess the data's reliability, and descriptive and gap analyses were performed using SPSS software and spreadsheets. Questionnaire survey used for this study in attached in Appendices 16.

3.10 Research Approach

Though it can be seen various research tools, methods to the research problem alter from each other and are characterized by own set of advantages and disadvantages (Dokuchaev, 2017). Focusing on Using and generating numerical data based on statistics is considered as the Quantitative approach (Saunders, Lewis, & Thornhill, 2016). Qualitative approach leads to imprisonment in-depth view and considerate of the respondents by exploring their practices, attitudes and performance or behavior, further to that it was stated that generalization of conclusions is not intended in most qualitative research (Dawson, 2007). The mixed approach of qualitative and quantitative approaches are used to respond to the weaknesses of them (Azorín & Cameron, 2010). In this study, the mix approach was used.

3.11 Summary

Commercial high-rise buildings that are brand-new are constructed to last for a longer time. Over the course of a building's lifespan, upgrades can be made, so it's important to make sure that fire protection systems are in place and that occupants are aware of the level of fire readiness required to meet the current conditions. It must adhere to current standards and Building and Construction Authority specifications (BCA). In this study, representatives were selected from a broad group of people using the Snowball sampling approach in order to analyze the fire readiness of 10 high rise commercial buildings during a five-year period. Relevant information gathered through a questionnaire survey after a preliminary survey based on the literature findings. Furthermore internal consistency, or how closely linked a group of items are to one another was measured using Cronbach Alpha in order to assess the validity and comprehensiveness of the data. Thus gap analysis was carried out utilizing spreadsheets and the SPSS software. Additionally, a hybrid approach combining qualitative and quantitative methods was used to carry out the study.

CHAPTER 4 - DATA PRESENTATION AND ANALYSIS

4.1 Introduction

This chapter consists of the study's analytical outcomes by converting primary data collected through questionnaires into detailed analysis. To achieve the aim of identifying fire readiness in Sri Lankan high rise commercial buildings and providing suggestions to improve fire readiness in high rise commercial buildings, a mixed research approach was used.

The thorough literature analysis , first identified several fire prevention strategies and systems presently installed and practiced in tall commercial structures. Later predefined fire protection strategies and systems were included in the questionnaire to see whether the identified fire protection strategies and systems were available with captioned buildings. As a result, information is gathered from hundreds of administrative members, including fire wardens, fire marshals, managers, team leaders, floor in charge, and department heads. The questionnaire included closed-ended questions, multiple-choice questions with a 5-point Likert scale, and open-ended questions. Cronbach Alpha was used to test the data's reliability, descriptive analysis, and gap analysis was carried out with the help of SPSS software and spreadsheets.

4.2 Summary of the responses

The data gathered from the questionnaire survey was analyzed using hundred respondents, and the table below summarizes the questionnaires distributed, responses received, and analyzed.

Table 4:1: Summary of the responses

No of questionnaires	Total
Distributed	130
Received	100

4.3 Reliability Analysis

4.3.1 Scale reliability test

Preceding to the comprehensive exploration, a reliability assessment was performed to examine the internal accuracy of the total scores of the variables. For some variables, several sub-factors were tested using a Likert scale, such as the vulnerability of occurring fire events in high-rise buildings, the impact of factors that affect fire readiness of high-rise building occupants, and the requirements to be filled for fire readiness of high-rise building occupants.

To define the specific variable, it is therefore necessary to calculate how closely the sub variables under consideration are associated as a group. Cronbach alpha, the widely accepted method, is also used to calculate internal consistency in this case. Cronbach's alpha thus depends on the quantity of testing tools of a particular study, the mean covariance among pairs of items, and the overall variance of the score.

If all scale items are independent of one another, the Cronbach alpha esteem is zero, and if covariance occurs, it is one. Cronbach's alpha > 0.9 – excellent, Cronbach's alpha > 0.8 – good, Cronbach's alpha > 0.7 – acceptable, Cronbach's alpha > 0.6 – questionable, Cronbach's alpha > 0.5 – poor, Cronbach's alpha 0.5 – unacceptable, according to George and Mallery (2003). According to the findings, the Cronbach Alpha of all four variables exceeds 0.7, with three variables having acceptable internal consistency and one variable having good internal consistency.

Table 4:2: Cronbach's alpha of the variables

Variable	Cronbach's Alpha	Number of Items
Vulnerability of occurring fire events in the high-rise building	.724	4
Fire readiness of the occupants	.726	11
Individual requirements to be filled for fire readiness of the occupants in high rise buildings	.816	6
Organizational requirements to be filled for fire readiness of the occupants in high rise buildings	.702	12

4.3.2 Inter Item Correlation Matrix

Another measure of reliability analysis performed prior to comprehensive analysis is the inter item correlation matrix. The inter item correlation matrix determines whether each sub variable is correlated to one another in order to ensure that all scale items measure the same variable.

4.3.3 Vulnerability of occurring fire events

According to the results of the inter item correlation matrix, all four factors of vulnerability of occurring fire events in high-rise buildings measure the same characteristics because all of the coefficients are positive.

Table 4:3: Inter Item Correlation Matrix

Inter-Item Correlation Matrix

	Function of the building	Physical structure of the building	Behaviors of the occupants	Management process
Function of the building	1.000	.152	.291	.077
Physical structure of the building	.152	1.000	.018	.057
Behaviours of the occupants	.291	.018	1.000	.060
Management process	.077	.057	.060	1.000

4.3.4 Requirements to be fulfilled for fire readiness

- **Occupants Awareness**

The Occupants Awareness that must be fulfilled for the fire readiness of the occupants in high rise buildings is tested in the questionnaire. According to the results of the inter item correlation matrix, it is clear that all of the scale items are contributing to measuring the individual requirements that must be met for the fire readiness of the occupants in high-rise buildings, as all of the coefficient values are positive. The following are the test points:

IR 1 : Knowledge of Occupants regarding fire

IR 2 : Familiarity of the building

IR 3 : Familiarity of the fire safety measures

IR 4 : Willingness to participate for fire training

IR 5 : Ability to respond immediately in an event of fire

IR 6 : Peril - event behavior of the occupants

Table 4:4: Inter Item Correlation Matrix

Inter-Item Correlation Matrix

	IR1	IR2	IR3	IR4	IR5	IR6
IR1	1.000	.310	.324	.042	.067	.022
IR2	.310	1.000	.147	.088	.209	.036
IR3	.324	.147	1.000	.178	.015	.092
IR4	.042	.088	.178	1.000	.191	.296
IR5	.067	.209	.015	.191	1.000	.099
IR6	.022	.036	.092	.296	.099	1.000

- **Building Requirements**

The following table shows the inter item correlation matrix developed for building requirements to be filled for fire readiness in high rise commercial buildings. Since all the coefficient values are positive it can be concluded that all the scale items contribute to characterize the building requirements to be fulfilled. Followings are the testing points,

OR 1: Plans for conducting fire training and awareness programmes

OR 2 : Plans for conducting fire drills

OR 3 : Plans for conducting fire risk assessment

OR 4 : Availability of fire safety policies and other written information

OR 5 : Worksite compliance regarding fire safety in high rise buildings

OR 6 : Designated personal for fire safety

OR 7 : Communication and coordination of fire events

OR 8 : Level of concern on social disorganization

OR 9 : Management and co-worker participation in fire drills and other trainings

OR 10 : Specific plans for evacuating people with disabilities

OR 11 : Provision of evacuation equipment for people with disabilities

OR 12 : Maintenance of fire protection systems

Table 4:5: Inter-Item Correlation Matrix

Inter-Item Correlation Matrix

	OR1	OR2	OR3	OR4	OR5	OR6	OR7	OR8	OR9	OR10	OR11	OR12
OR1	1.000	.109	.312	.274	.302	.302	.348	.213	.152	.332	.244	.265
OR2	.109	1.000	.143	.184	.341	.208	.144	.337	.324	.465	.230	.216
OR3	.312	.143	1.000	.412	.385	.349	.175	.347	.291	.305	.341	.203
OR4	.274	.184	.412	1.000	.406	.441	.471	.331	.271	.361	.318	.383
OR5	.302	.341	.385	.406	1.000	.334	.471	.496	.542	.346	.290	.265
OR6	.302	.208	.349	.441	.334	1.000	.401	.369	.330	.209	.278	.338
OR7	.348	.144	.175	.471	.471	.401	1.000	.367	.260	.293	.238	.299
OR8	.213	.337	.347	.331	.496	.369	.367	1.000	.430	.393	.384	.297
OR9	.152	.324	.291	.271	.542	.330	.260	.430	1.000	.448	.347	.412
OR10	.332	.465	.305	.361	.346	.209	.293	.393	.448	1.000	.361	.335
OR11	.244	.230	.341	.318	.290	.278	.238	.384	.347	.361	1.000	.495
OR12	.265	.216	.203	.383	.265	.338	.299	.297	.412	.335	.495	1.000

4.4 Background study of the respondents

The questionnaire was distributed to fire wardens, fire marshals, managers, team leaders, floor in charge, and department heads, with 100 serving as the target sample size in this study.

4.4.1 Level of experience

The below table outlines the total number of responses received and it is evident that there are 100 valid responses out of 130questionaire surveys distributed that can be used in the analysis.

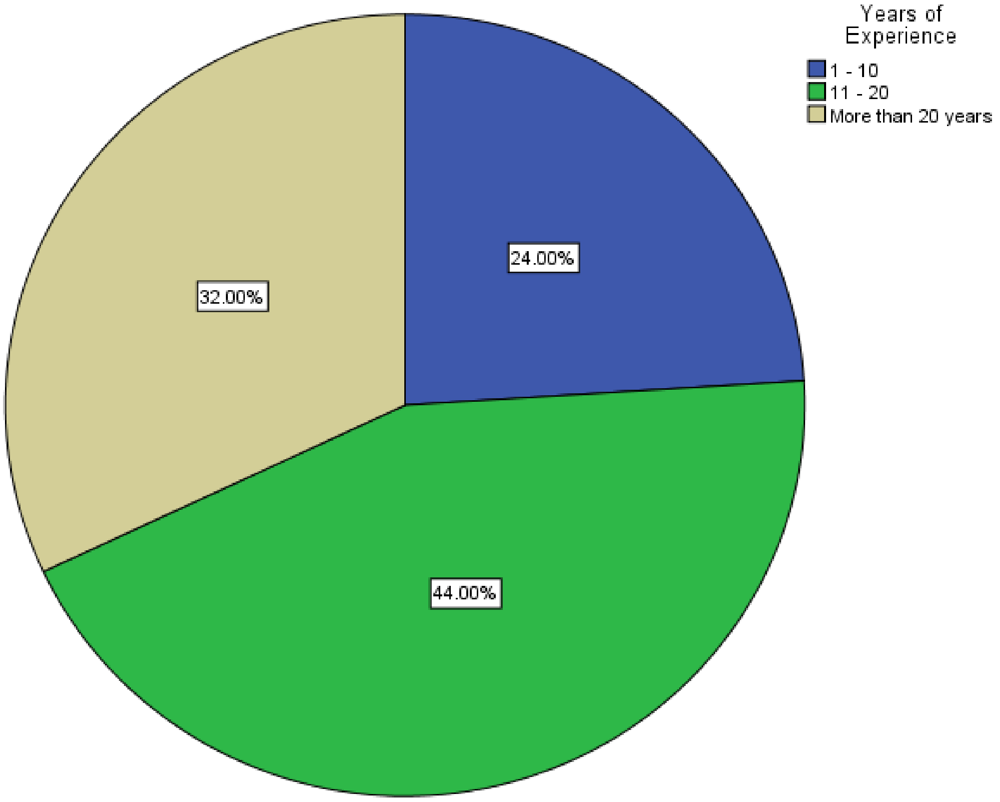


Figure 4.1: Level of experience

According to the respondent's working experience in high rise buildings, the majority of respondents have 11 – 20 years of experience. The second highest frequency is recorded for respondents with more than 20 years of experience, with the lowest frequency accounting for 24 percent for respondents with 1 to 10 years of experience. Based on this analysis, it is possible to conclude that the respondents have adequate industry knowledge.

4.5 General Overview of the High-Rise Buildings considered

The characteristics of the high-rise building considered in the study are evaluated in this section based on the number of floors, the number of stairs, and the number of elevators available in the building.

4.5.1 Number of elevators in the building

The presence of the fireman elevator in the building was determined based on the number of elevators. How many elevators can be used as fireman elevators in the event of a fire is crucial. Elevators are used by the fire department during a building fire, and after apparatus and stairs, elevators are the third most popular mode of transportation for fire fighters. The elevator cab is made to descend to the ground floor when the fire service mode is engaged. The elevator is built to return the cab to a different floor if smoke is detected on the ground floor.

The table 4.6 below depicts the number of elevators available in the building. According to the analysis, the highest percentage of 22 % is recorded for buildings with four elevators, 21 % for buildings with three elevators, and 17 % for buildings with two elevators. A similar 13 % is recorded for buildings with five and six elevators. Only 2% of the structures do not have an elevator.

Table 4:6 : Number of elevators in the building

Statistics

How many elevators are there in your building?

N	Valid	100
	Missing	0
Mean		3.400
Median		3.000

How many elevators are there in your building?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.0	2	2.0	2.0	2.0
	1.0	12	12.0	12.0	14.0
	2.0	17	17.0	17.0	31.0
	3.0	21	21.0	21.0	52.0
	4.0	22	22.0	22.0	74.0
	5.0	13	13.0	13.0	87.0
	6.0	13	13.0	13.0	100.0
	Total	100	100.0	100.0	

4.6 Vulnerability of occurring fire events in the high-rise building

The table 4.7 below, depicts the number of elevators available in the building. According to the analysis, the highest percentage of 22 % is recorded for buildings with four elevators, 21 % for buildings with three elevators, and 17 % for buildings with two elevators. A similar 13 % is recorded for buildings with five and six elevators. Only 2% of the structures do not have an elevator.

Table 4:7: Vulnerability of occurring fire events in the high-rise buildings

Factor	Level of effect				
	Never affect	Rarely affect	Sometimes affect	Very often affect	Always affect
Function of the building	1%	7%	25%	34%	33%
Physical structure of the building	1%	6%	27%	36%	30%
Behaviours of the occupants	0%	2%	28%	41%	29%
Management process	0%	4%	49%	27%	20%

4.7 Current fire readiness of the high-rise buildings

Emergency response is easier when everyone knows their respective responsibilities. Establish a detailed fire emergency evacuation plan that dictates how to respond, when to respond, and identifies a path of egress. If occupants have special needs or require special attention, address these details in the plan.

Most notably, a question is included in the survey to determine the level of fire readiness in Sri Lanka's tall commercial buildings. The level of preparedness for fires is determined by the precautions taken to stop fires from spreading. Passive systems and active systems are the two categories into which fire protection systems are categorized in the literature (ICTAD/SCA/9, 2014). The respondents were then asked if any specific fire safety systems were present in their building.

4.8 Active fire protection systems

The questionnaire was used to assess the availability of eight active fire protection systems. According to the findings, only 1% of buildings have reported a lack of sprinkler systems, and in 99 % of cases, this fire protection system is available within the building. According to Marty Ahrens (2017), the death rate per 1,000 reported fires was 87 percent lower in sprinkled properties than in properties without Active fire protection system, and the rate of civil injury in sprinkling properties was 27% smaller and the firefighter rate of fire field injury was 67% lower than for fires in properties with no Active fire protection system.

Fire alarm systems, like all other types of electronic equipment, are rapidly evolving and improving in terms of effectiveness. According to the findings, 96 % of respondents have documented the presence of fire alarm systems in their building.

In terms of the availability of fire extinguishers within the building, 96 percent of respondents agreed, while only 4 % reported a lack of fire extinguishers within their buildings. Only 90% of buildings have recorded the availability of a hydraulic hose reel system, and at least one hydraulic hose reel shall be provided in every story of every building, unless the building exceeds a maximum height of 18m.

Total flooding system does not appear to be a popular fire prevention strategy in the Sri Lankan context, where the majority of 54 % have reported total flooding system non-availability within the building premises. Active fire protection system availability and the frequency have been showed in the Table 4.8.

Fire hydrants and call point systems are sufficiently available within the considered building premises, with 91 % and 93 % agreeing on their availability within the buildings. The majority of 52 % have mentioned the absence of fire suppression systems within the building's premises.

Table 4:8 : Active fire protection systems

	Availability	Frequency
Sprinkler system	No	1
	yes	99
Fire alarm system	No	4
	yes	96
Fire extinguishers	No	4
	yes	96
Hydraulic hose reel system	No	10
	yes	90
Total flooding system	No	54
	yes	46
Fire hydrants	No	9
	yes	91
Fire suppression systems	No	52
	yes	48
Call point systems	No	7
	yes	93

4.9 Passive fire protection systems

Only 88 percent of the buildings have recorded availability of fire doors and walls under passive fire protection systems. However, fire dampers were found in only 56% of the cases. These are necessary to prevent the spread of fire, particularly inside ductwork through fire-resistant walls and floors. In terms of fire resistance, smoke dampers are very similar to fire dampers.

The availability of penetration seals is not satisfactory, with only 50% of cases found to be available within buildings. Exit passages, exit signage, and exit doors are all available in 96 %, 95 %, and 95 % of cases, respectively. In 79 % of cases, travel distance was considered as a fire prevention technique when designing the building.

Table 4:9 : Passive fire protection systems

	Availability	Frequency
Fire doors and walls	No	12
	yes	88
Fire dampers	No	44
	yes	56
Penetration seals	No	50
	yes	50
Emergency staircases	No	10
	yes	90
Exit passages	No	4
	yes	96
Exit signage	No	5
	yes	95
Exit doors	No	5
	yes	95
Travel distance	No	21
	yes	79

4.10 Requirements to be fulfilled for fire readiness in high rise buildings

To identify the gaps in high-rise commercial buildings pertaining to occupant fire readiness, two factors, namely occupant awareness and building requirements, which must be filled for occupant fire readiness in high rise buildings, were identified. The identified requirements were included in the questionnaire, and respondents were asked to rank them based on how well those requirements were met in their organization.

4.10.1 Awareness for building's occupants

The figure 4.2 below depicts the level of occupant awareness that must be filled in order for high-rise building occupants to be fire ready. It also identifies the gaps in occupant fire readiness in commercial high-rise buildings. According to the findings, occupants' awareness of IR 3 "Familiarity of the fire safety measures within the building" and IR 1 "Knowledge of the occupants regarding fire safety" is less than 80%. All other individual requirements, such as IR 2: Building familiarity, IR 4: Willingness to participate in a fire training program, and IR 5: Ability to respond immediately in the event of a fire, must be met (Emergency Preparedness) and IR 6: peril event behaviours of the occupants (e.g. seeking out others, gathering personal items, answering phone calls etc.) are above 80% fulfillment. After thorough examination, all values were calculated using the questionnaire replies.

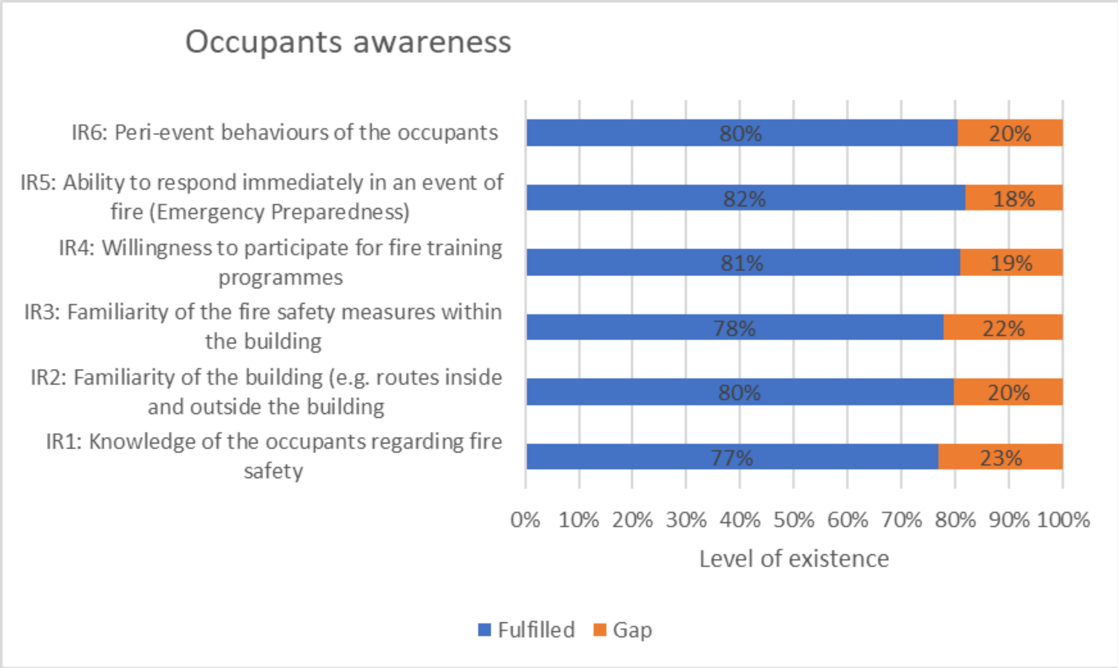


Figure 4.2 : Occupants awareness

4.10.2 Building Requirements

The level of fulfillment of the building requirements to be filled for the fire readiness of high-rise building tenants is shown in figure 4.3 below. The results demonstrate that all organizational needs are more than 80% complete, except for building requirements OR11: Provision of evacuation equipment for individuals with disabilities and OR1: Plans for conducting fire training and awareness programs. After thorough examination, all values were calculated using the questionnaire replies.

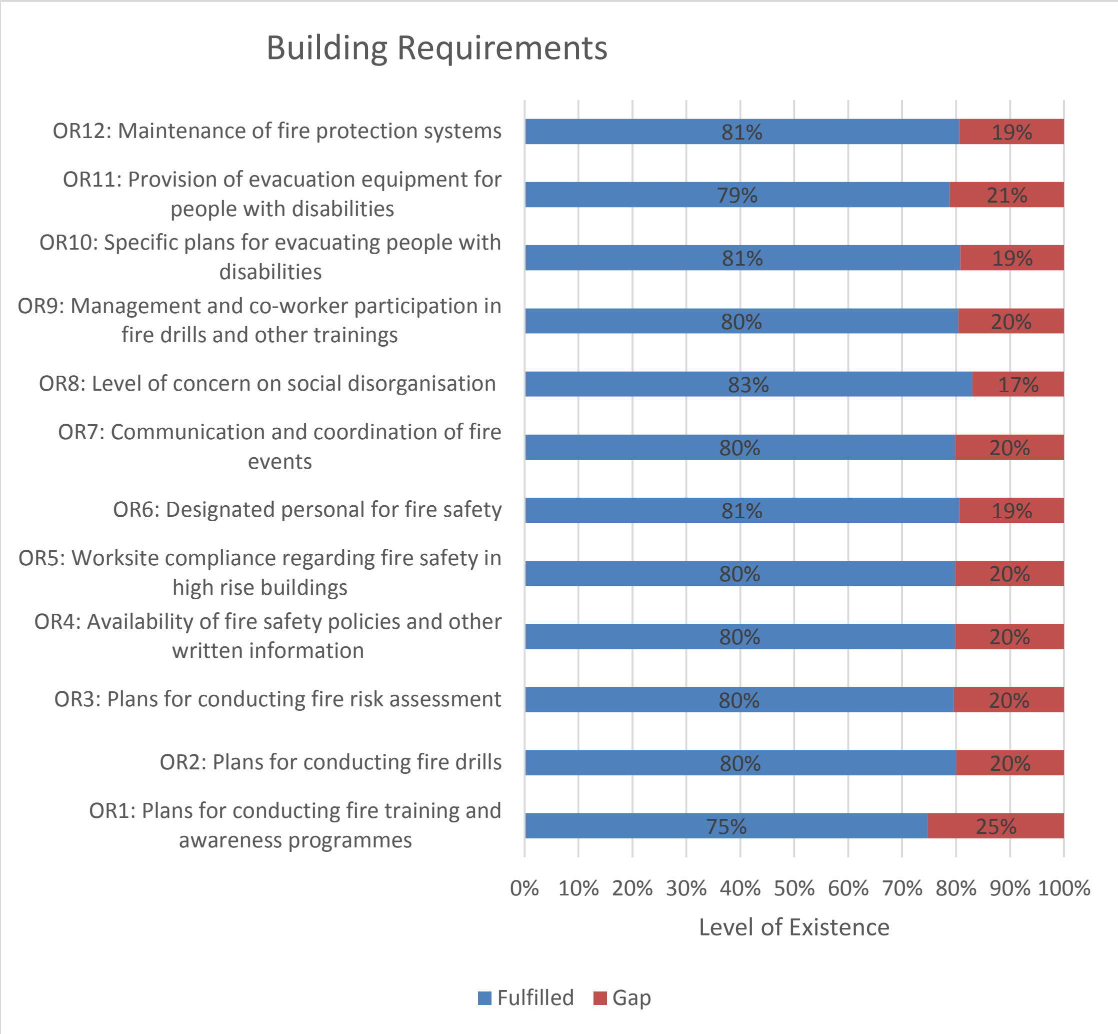


Figure 4.3: -Building Requirement

4.11 Recommendations to enhance fire readiness in high rise commercial buildings in Sri Lanka.

Under active fire protection systems, it is clear that total flooding and suppression systems are unfamiliar with fire prevention practices in Sri Lankan high-rise buildings. The total flooding system is an environmentally friendly technique with no or low human toxicity, ozone depletion potential, and global warming potential. As a result, promoting such methods would be beneficial to Sri Lanka. Furthermore, under passive fire protection systems, penetration seals are a little-known but effective fire-stopping technique in Sri Lanka. Fireproof and separating elements play a significant role in reducing the impact of the fire on the primary building structure, reducing the degree to which it is dispersed by dividing the building into fire proof compartments. When considering occupants' awareness of fire readiness in high-rise buildings, more emphasis should be placed on improving familiarity with the building's fire safety measures and occupants' knowledge of fire safety. When responding to the questionnaire, more than 60% of respondents requested the creation of Emergency Rescue Teams (ERT) and frequent fire drills.

4.12 Chapter Summary

This chapter used descriptive statistics, reliability analysis, and gap analysis with SPSS and spreadsheets to analyze the collected data. According to the findings, vulnerability is the most affected of the four factors. The occupants' behaviors have the greatest impact on the Vulnerability of occurring fire events in high-rise buildings. Furthermore, total flooding systems and fire suppression systems do not appear to be popular fire prevention strategies in the Sri Lankan context, based on current fire readiness of high-rise buildings. Furthermore, individual requirements to be fulfilled, such as "familiarity with the fire safety measures within the building" and "knowledge of the occupants regarding fire safety," are less than 80% fulfilled. Furthermore, organizational requirements such as the provision of evacuation equipment for people with disabilities and plans for conducting fire training and awareness programs are only met to a lesser extent than 80 % of the time.

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The previous chapter focused on a detailed review, whereas this chapter articulates critical research findings and makes recommendations to update research goals and explain how the study met those goals. Finally, the study's limitations and future research directions are defined in relation to this subject.

5.2 Conclusions

This empirical study's main goals are to assess Sri Lanka's high-rise commercial buildings' fire preparation for emergencies and to offer suggestions for enhancing such readiness. In order to accomplish this aim, four sub-goals were created, as stated below.

Objective 1: Review the strategies that currently adopted in high-rise buildings to prevent fire

An extensive analysis of the literature that identifies the numerous techniques that are common in the global setting is used to address the first objective. Active fire protection systems include sprinkler systems, fire alarm systems, fire extinguishers, hydraulic hose reel systems, total flooding systems, fire doors and walls, fire dampers, penetration seals, and emergency staircases.

Objective 2: Identify the fire readiness in high-rise commercial buildings in Sri Lanka

In high-rise commercial buildings, the presence of fire prevention systems on the property has been used to gauge how prepared the inhabitants are for an emergency. The results show that entire flooding systems, fire suppression systems, fire dampers, and the availability of penetration seals are not utilized in Sri Lankan high rise buildings to a suitable degree.

Objective 3: Identify the gaps existing in high-rise commercial buildings

The questionnaire, which request respondents to assess the compliance of those standards in their high-rise buildings, identifies and tests the gaps in fire readiness and building requirements. Less than 80% of the residents were found to be aware of "familiarity with the fire safety measures within the building" and to have "knowledge of the occupants regarding fire safety." While plans for "supply of evacuation equipment for people with disabilities" and programs for fire training and awareness are less than 80% of what is required for buildings.

Objective 4: Suggest workable steps to increase the fire readiness of commercial high rise buildings

Finally, suggestions are made for enhancing high-rise building fire readiness, including the promotion of suppression systems and environmentally friendly total flooding systems. The familiarity of the fire safety measures within the structure and the residents' understanding of fire safety should be improved when assessing the unique needs to be met for fire readiness in high-rise commercial buildings. It's suggested to establish Emergency Rescue Teams (ERT) in addition to organizing regular fire drills.

5.3 Recommendations

Grey zones in fire readiness could be seen in many commercial high-rise buildings as a result of the conflicting criteria. Current fire safety standards must be periodically updated as necessary to address these conditions. However, in Sri Lanka, by the time the majority of the high-rises were built, local fire codes lacked the necessary protections to protect those kinds of structures.

The findings of this study are crucial because they shed light on how commercial high-rise structures behave in terms of fire readiness . Public health will benefit from increased public understanding of fire safety precautions since it will help medical practitioners and other experts reduce the risk of fire in high-rise structures. The results of this study can be used to future fire safety regulations, programs, and health initiatives.

5.4 Limitations

Because of time constraints, the study was limited to 100 samples. Furthermore, the study only focuses on the fire readiness of high-rise commercial buildings, which were sampled in a convenient manner. As a result, the generalizability of the result is limited. As a data collection tool, a questionnaire survey has some limitations, such as not allowing for different perspectives.

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APPENDICES

Fire Readiness Questionnaire

Section 01: General Information

1. Designation of the respondent:
2. Years of experience in industry:

Section 02: General Overview of the High Rise Building

1. Vulnerability of occurring fire events in the high rise buildings

Following table presents the factors affect for the vulnerability of occurring fire events in high rise buildings. Based on your experience, please tick the most appropriate scale regarding your organization.

Factor	Never affect	Rarely affect	Sometimes affect	Very often affect	Always affect
Function of the building					
Physical structure of the building					
Behaviors of the occupants					
Management process					

Section 03: Current fire readiness of the occupants in high rise buildings

2. The following table presents the fire protection systems which can be available within high rise buildings for fire safety. Please indicate the use of those fire protection systems in your organization.

Active fire protection system *is defined as a system in action to extinguish a fire which is activated by manually or automatically.*

Passive fire protection system *is defined as an integral part of the structure of the building for fire safety.*

	Yes	No
Active fire protection systems		
Sprinkler system		
Fire alarm system		
Fire extinguishers		
Hydraulic hose reel system		
Total flooding system		
Fire hydrants		
Fire suppression systems		
Call point systems		
Other (If any)………………………		
Passive fire protection systems		
Fire doors and walls		
Fire dampers		
Penetration seals		
Emergency staircases		
Exit passages		

Exit signage		
Exit doors		
Travel distance		
Other (If any)………………………		

3. **Factors affect for the fire readiness in high rise buildings**

The following table presents the factors which can affect for the fire readiness in high rise buildings. Based on your current building experiences, please tick the most appropriate scale with regarding your organization.

Individual Factor	**Never affect**	**Rarely affect**	**Sometimes affect**	**Very often affect**	**Always affect**
Evacuation and safety related beliefs and attitudes of the occupants					
Job characteristics of the occupants					
Health and injury status of the occupants					
Prior emergency experiences					
Peril-event behaviors and activities of the occupants					
Socio demographic factors (e.g. age, marital status, education, responsibilities etc.)					
Environmental conditions during the evacuation (e.g. poor lighting, dust or debris, overcrowding etc.)					
Poor, missing or confusing signage					
Operability status of fire protection systems					

Time for evacuation of the occupants					
Lack of directions out of building					

4. Requirements to be filled for fire readiness in high rise buildings

The following tables present the requirements which have to be filled for the fire readiness in high rise buildings. Based on your experiences, please tick the most appropriate scale with regarding the fulfillment of those requirements in your organization.

Occupants awareness *refer the things that should be properly fulfilled by the occupants as an individual person.*

Occupants awareness	**Very less**	**Less**	**Moderate**	**High**	**Very high**
Knowledge of the occupants regarding fire safety					
Familiarity of the building (e.g. routes inside and outside the building)					
Familiarity of the fire safety measures within the building					
Willingness to participate for fire training programmes					
Ability to respond immediately in an event of fire (Emergency Preparedness)					
Peri-event behaviors of the occupants (e.g. seeking out others, gathering personal items, answering phone calls etc.)					

Building requirements *refer the things that should be properly fulfilled by the management on behalf of the organization.*

Building Requirements	**Very less**	**Less**	**Moderate**	**High**	**Very high**
Plans for conducting fire training and awareness programmes					
Plans for conducting fire drills					
Plans for conducting fire risk assessment					
Availability of fire safety policies and other written information					
Worksite compliance regarding fire safety in high rise buildings					
Designated personal for fire safety					
Communication and coordination of fire events					
Level of concern on social disorganization (e.g. people screaming, fighting for elevators etc.)					
Management and co-worker participation in fire drills and other trainings					
Specific plans for evacuating people with disabilities					
Provision of evacuation equipment for people with disabilities					
Maintenance of fire protection systems					

Any other comments:

Thank you for your valuable time spent on this questionnaire