Fire Safety Performance of High-rise buildings in Sri Lanka

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ABSTRACT

Fire safety is the most critical aspect of high-rise building safety. As human life is essential than other aspects, analysis of a reliable building fire safety performance is more critical than ever. Whenever an actual fire incident occurs, the active firefighting systems in the building would be activated first. As a result, it is necessary to identify the operation of active firefighting systems as well as proper service and maintenance of the systems.

The research problem was identified as, people tend to fulfill the minimum fire safety requirements imposed by regulations. Therefore, the condition of fire safety performance in most high-rise buildings are very poor. The aim of this research is to identify suggestions to improve the fire safety performance in high-rise buildings in Sri Lanka. Consequently, three objectives have been established to fulfill the research aim. In the first objective, building design features, human behaviors, equipment failures, and underperformance of fire regulations are highlighted as contributing factors to building fire events. The second objective evaluates fire safety precautions implemented in high-rise buildings, such as alarm activation, communication and evacuation procedures, service and maintenance periods of live fire systems, and fire evacuation drills. In the third objective, suggestions to improve the fire safety performance in high-rise buildings are recognized as, maintaining proper coordination between the fire brigade and building fire maintenance department at all times. Since the interpretivism philosophy used in this inductive qualitative research, the data was collected through conducting ten interviews with professionals who are primarily engaged with achieving reliable fire safety performance in high-rise buildings.

In conclusion, recommendations such as, establish a coordination center to maintain proper coordination with fire brigade, air force and building maintenance staff and introduce a trained air force squad with helicopters and firefighting equipments can be implemented in Sri Lankan high-rise buildings.

KEYWORDS: *fire safety, high-rise buildings, construction*

1 INTRODUCTION

With the growth of the economy, increased population density and demand for building spaces, it is unavoidable that buildings in large cities will have to rise higher and higher (Chow, 2005). In Sri Lanka, a high-rise building is described as one that is between 30m up to 60m in height and super high-rise building is defined as one that is more than 60m in height (Colombo Municipal Council, 2017). High-rise structures have 3 unique features: first, the structure is complex due to its height and number of floors, second, the operations are complex, and the population size is large and third, combustible is massive, and the fire load is great (Liu et al., 2012).

The goal of Architects and builders is to develop a structure that will last for more than 60 years (Rathnayake et al., 2020). However, the aim fails for a variety of reasons, the most important of which

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is fire. Although, in terms of working or living in high-rise buildings, large scale fires have not been widespread in recent history of Sri Lanka, so the emphasis on fire safety may not be as high as desired (Aluthwala et al., 2007). Since Sri Lankan fire brigade is not equipped with modern technologies when compared with developed countries, it is an important part in high-rise buildings to install and maintain a proper fire and safety systems to minimize risks of life.

Every building has a fire risk. Therefore, it is a mandatory requirement to take fire system requirements from Fire Service Department before commencement of any construction project (Urban Development Authority, 2018). Typical fire requirements are as follows: fire detection system, fire hydrant system, sprinkler system, fire suppression system, one way communication system, two-way communication system, portable fire extinguishers, staircase pressurization system and evacuation system (Colombo Municipal Council, 2017a) .

The research problem was identified as, people tend to fulfill the minimum fire safety requirements imposed by codes and regulations due to the high cost of installation and maintenance of fire safety systems in high-rise buildings. Therefore, the condition of fire safety performance in most high-rise buildings are very poor. As a result, to achieve the research problem, the aim of this research is more focused on fire safety performance in high-rise buildings. The aim of this research is to identify suggestions to improve the fire safety performance in high-rise buildings in Sri Lanka. Three objectives have been set to achieve the aim. The first objective is to identify factors contributing to building fire incidents, second objective is to analyze fire safety precautions implemented in Sri Lankan high-rise buildings and the third objective is to identify suggestions to improve the fire safety performance in Sri Lankan high-rise buildings. The objective one was achieved by reviewing a literature review. The second and third objectives were completely achieved by conducting expert interviews. Conclusions and recommendations were based on the findings from the third goal.

2 LITERATURE REVIEW

A detailed review of the literature was conducted to examine the factors that have the greatest impact on building fire events. Therefore, to enhance the fire safety performance in high-rise structures, it is necessary to analyze the factors that contribute to fire incidents in high-rise buildings.

2.1 The connection between High-rise buildings and Fires

Accordingly, why is it such a critical criterion to be concerned about fires in high-rise buildings? Since there are so many stairways, elevators, pipelines, air passageways, cables as well as other vertical shafts in a high-rise structure, fire spreads quickly than low-rise structures (Liu et al., 2012). As there is so much combustible material around, if it takes fire, it will spread rapidly. All these factors make evacuation more difficult due to the high population density and limited evacuation time in high-rise buildings.

When concerning about the high-rise buildings fire safety, the following systems must be operated properly, otherwise high-rise buildings become more vulnerable in case of a real fire. Fire safety systems include staircase pressurization system, sprinkler system, alarm system, two communication system as well as properly marked evacuation paths and proper operation of firefighter lifts will help to save human lives. Therefore, to enhance the fire safety performance in high-rise buildings, it is necessary to analyze the factors that contribute to fire incidents in high-rise buildings.

2.2 Building Design Features

Building design features have a major impact on fire safety. Architect is the person who mainly responsible for the building's design features. In fact, from the perspective of an architect, fire safety would most probably be a less considerable factor compared to the aesthetic appearance of the building. Fire safety is a critical need that is sometimes given a lesser value than other design requirements because of its inherent qualities and the low degree of danger experienced by fire. Grenfell Tower, a 24-storey residential building in London, that caught fire in 2017, killing 72 people, is a great example of a fire caused by building design features (Mohamed et al., 2019). The main reason for the Grenfell Tower fire is the exterior modern wall cladding, which is a key factor to the fast spread of the fire. Moreover, after a fire incident at the Crowne Plaza Hotel in Denmark reported that firefighters took approximately

8 minutes to find the door to the fireman's elevator (Rathnayake et al., 2020). At the investigation process, investigators discovered that the reason for taking a long time to find a door was due to the absence of proper naming on the fireman's elevator, as well as the fact that the door and its background walls had the same colour, which make difficult to identify the door. However, if a fire occurs, this design error causes a significant delay in the rescue process.

2.3 Human Behavior

Fires in high-rise structures may be caused by wrong human behavior. The Hong Kong fire incident in a high-rise building further revealed that the floor at the bottom of the lift shaft was suspected to include garbage, papers, and waste materials, posing a significant fire risk (Wong and Lau, 2007). In addition, when it comes to the long-term operation of high-rise buildings, some repairs may be necessary, therefore welding works with electric discharges was identified as a source of ignition with highly combustible components. Human errors include wrong waste disposal, careless electrical tool maintenance, faulty wiring, irresponsible workers etc. Furthermore, failing to use the facility for its intended purpose was recognized as a fire cause in high-rise buildings. A fire destroyed a 28-story Shanghai apartment building in China on November 15, 2010, killing at least 53 individuals and injuring 90 others (Barboza, 2010). According to the investigation, the cause of the fire was identified as sparks from welding work being carried out by unlicensed welders on the building.

2.4 Equipments Failures

Equipment failures, such as failures in cooking equipments, heating equipments and electrical and lighting devices are another leading cause for high-rise building fires. (Ahrens, 2016). When concerning the buildings with cooking equipments, fires occur due to excessive cooking temperatures, explosive oils and grease and the busy environment of commercial kitchens. Furthermore, depending on the climate, high-rise buildings may require heat for several months of the year, putting them at risk of fire due to overheating. Not only that, but also old and defective circuits, heavily loaded circuits, defective fuses, poor connections, unbalanced electrical equipments and variety of other electrical and lighting issues, can result in overheating or sparks, which can start a fire. The 42-story Polat Tower in Istanbul, which contains apartments as well as shops and businesses, caught fire on July 17, 2012 (Goodenough, 2012). The fire, which was reported to have been started by a faulty air conditioner, was successfully extinguished by firemen who had battled the flames for hours and incredibly no one was injured from the fire.

2.5 Underperformance of Fire Regulations, Policies and Building Codes

Fire safety regulations and building codes are primarily responsible for maintaining building fire safety. However, landowners and responsible parties tend to fulfill the minimum fire safety standards outlined in rules or regulations due to the high capital cost of fire safety systems (Li and Zlatanova et al., 2007). As a result, attempting to comply with the provisions without recognizing the logical basis behind the regulations would result in ineffective building fire safety. In order to further clarify this factor, policies expect that occupants will use the nearest emergency exit to escape, but occupants will generally escape by familiar exit routes, rather than using emergency exits, as it has been proven that known escape routes are shorter than unknown escape routes. The Markham Tower, a 10-story building in Norwich, was affected by a fire in February 2011 (Maxwell, 2017). The reason of the incident was discovered as the flats were equipped with battery-operated smoke detectors and the building had an up-to-date fire risk assessment but was not equipped with a sprinkler system.

3 RESEARCH METHODOLOGY

This section identifies the appropriate research methods for fulfilling the research aim and objectives (Langkos, 2014). This research is based on fire safety performance of high-rise buildings in Sri Lanka. Initially it is important to review the literature in order to identify factors contributing to building fire incidents. Then, define the research problem by identifying the research gap from previous research studies. After defining the research problem, formulate research aim and objectives that will specify what should be investigated and provide a framework for the scope of research study. In the next

stage, preparation of the research design which is a blueprint that lays out the methods and techniques for collecting, processing and analyzing the relevant data. Accordingly, identify data collection methods and then set data analysis methods to determine whether the research aim, objectives and research question has been properly achieved. Finally, suggest recommendations and conclude the research study.

Research design outlines the process for gathering and analyzing the required information, as well as how all of this will be used to address the research question (Boru, 2018). Semi-structured interviews were used to obtain data for this research study in order to recognize real, human experiences based on achieving proper fire safety performance in high-rise buildings. In this research study, data will be collected through the qualitative approach to research design. Whereas interviewing is a technique used to understand the experiences of construction industry professionals, which is considered as a method for conducting qualitative research. In the research approach section, there are two types of approaches: inductive and deductive (Priya Chetty, 2016). As qualitative data is obtained for this research study, inductive approach is selected to analyze the data. Inductive approach is based on knowledge from expert interviews that leads to the generalization of a theory about the fire safety performance of high-rise buildings in Sri Lanka. Saunders (2009) has recognized five major research philosophies: positivism, critical realism, interpretivism, postmodernism and pragmatism. Interpretivism was selected as the most appropriate research philosophy for this research study, based on the reason that expert interviews were conducted to develop theory using participants' perceptions and meanings, as well as how they differ from those of other participants. Subsequently, they are two types of sampling methods: probability sampling and non-probability sampling (Shona McCombes, 2019). The sample group for this research study is made up of individuals with more than ten years of experience and knowledge in the area of fire safety in high-rise buildings. As a result, non-probability sampling was selected, since every construction industry professional is not knowledgeable of high-rise building fire safety. Therefore, individuals are selected based on non-random factor, and not every individual has a possibility of being included. The qualitative data obtained through expert interviews with ten respondents will be evaluated in the data analysis section. In this study, ten interviewees with more than ten years of experience in the field of fire safety, participated to share their knowledge about fire safety performance in high-rise buildings.

Table 1. Profile of the Interviewees

Interviewee ID	**Profession**	**Professional Qualifications**	**Experience in the Construction industry**
R1	Chief Fire Officer	FIFireE(UK)	30 years
R2	Fire Consultant	FIFireE(UK)	48 years
R3	Fire Chief	GIFireE(UK)	40 years
R4	General Manager in MEP Division	B.Sc.Eng(Hons) in Mechanical, CEng	30 years
R5	Contracts and Procurement Manager	B.Sc.QS(Hons), Chartered QS	11 years
R6	Mechanical Engineer	B.Sc.Eng.(Hons) in Mechanical	16 years
R7	Facility Manager	Dip.in Fire Engineering (SABIC)	25 years
R8	Senior MEP Manager	Dip.in Fire Engineering (UK)	15 years
R9	MEP Project Manager	B.Sc.Eng.(Hons) in Mechanical	16 years
R10	MEP Project Manager	HND in Mechanical Engineering	12 years

4 FIRE SAFETY PRECAUTIONS IMPLEMENTED IN SRI LANKAN HIGH-RISE BUILDINGS

This section mainly focuses on achieving the second objective in the research study. As a result, data collected from semi-structured interviews with industry professionals are used to achieve this objective.

4.1 Alarm activation and communication steps in case of a fire in particular floor of the high-rise building

In case of a fire, the fire alarm tone may be activated manually by a pull station or manual call point, or automatically through the use of heat and smoke detectors, which then sound the evacuation alarm, alerting the people in that zone to the risk of a fire. In the event of a fire, the fire alarm panel indicates the correct location of the fire, assisting emergency personnel as well as the fire brigade in locating the fire as soon as possible. Then trained emergency personnel would evaluate the situation and broadcast specific orders through emergency voice communication system to the occupants. If it is a small fire, extinguish the fire using portable fire extinguishers or fire hose. If the fire cannot be extinguish using extinguishers, tenants of the fire floor, as well as those immediately above and below, should use the exit stairs to move to a safe location as soon as possible. People on other floors may be advised to remain in place and await further instructions. If the emergency increases in scale, the warnings can be expanded to evacuate the entire building. R8 interviewee highlighted that if there will be a partial or full evacuation will be decided by the progress of the fire, and the maximum evacuation time in a high-rise building should be three minutes.

4.2 Service and maintenance period of live fire systems

Sprinkler system should be checked weekly by the user, and annual testing should be carried out for the complete system by a competent person and certified by Authority having Jurisdiction (AHJ). The user should test the hydrant system on a monthly basis and conduct a visual inspection every six months, in addition to annual testing and certification by AHJ. Fire alarm system should be tested weekly by the user, and a competent person should test the alarm system every six months and carry out the annual testing and certified by the AHJ. Live fire systems should be checked every week by an in-housed building maintenance team.

R8 interviewee stated that “select a competent agent authorized by the manufacturer for the services and enter into a comprehensive maintenance agreement with the agent. All live fire systems must have minimum two comprehensive services within one year and service reports should be submitted for proper record by the service provider.”

4.3 Recommendations on how often high-rise buildings should conduct fire evacuation drills

A fire evacuation drill is a planned emergency process designed to imitate the procedures that would be followed in the case of a fire or other emergency that necessitates evacuation. It is important to conduct fire evacuation drills every three months in a workplace with serious fire hazards, such as high-rise buildings, while every six months is adequate in other workplaces. Announced drills are preferred by employees and supervisors may find it easier to organize the event and limit workflow disturbance while unannounced drills provide more realistic assessment of evacuation preparedness.

4.4 Fire evacuation procedures currently practicing in high-rise buildings

In the event of a fire in a high-rise building, occupants should first proceed to the corridors or lobbies, then either escape through a protected stairway to a fire assembly point or move to a refuge floor, which is located in every 10 floors. During the time when occupants are reported to the assembly point, fire warden should check to see if anyone is still inside the building premises. In the event of a fire, all elevators should be landed to the ground floor, since it would prevent occupants from using elevators as a means of escape, which is functioned by the fire alarm system. However, firefighters lift should be operated normally to rescue people who may be caught on upper floors and to suppress the fire.

According to R2 interviewee, staircase pressurization is a mandatory requirement for high-rise buildings that provide a smoke-free evacuation path and maximize occupant evacuation speed in the event of a fire. Hence, the issue is that as people escape during a fire, they must open the door to the stairway for a longer period of time, allowing smoke to enter the stairway. If the stairways are filled with smoke, evacuation may be difficult. If the staircase pressurization method is used, the higher pressure in the stairway pushes the smoke back onto the floor when the doors open, clearing the escape route of smoke.

R1 interviewee highlighted that, high-rise buildings are now equipped with a refuge floor at each ten stories for the disabled occupants and persons who need help should be directed to a refuge floor until fire fighters can remove those disable people. Furthermore, sounder strobes are installed for those with hearing problems, so that in an emergency, people with hearing difficulties can see the light emerging from the sounder strobe.

4.5 Suggestions to avoid panic conditions due to false alarm incidents frequently

In order to avoid false fire alarm incidents, install sounder to the Main Panel which is located at the Fire Command Center and programmed with the Main Alarm Panel to activate the sounder when there is a fire. Once sounder is activated, monitor the location of the fire by Main Panel and immediately inspect the location to find whether it is really a fire or any fault signal. If it is a real fire, activate all sounders by switch and if it is a fault signal, reset the panel. R1 interviewee commented that, fire alarm systems need regular testing and maintenance by a qualified technician as early protection against false fire alarm events and always maintain good communication with the fire service provider in the event of a false fire alarm incident. Additionally, to avoid panic conditions due to false fire alarm incidents, conduct awareness programs repeatedly, provide advance notice for the occupants regarding the participation of fire drills and train fire wardens or building maintenance staff to respond in such incidents.

4.6 Safety measures need to take if there are areas of special risk in high-rise buildings

A boiler room, generator room or transformer room or any other area of special risk should be separated from the rest of the building by a compartment that is fire resistant for at least 4 hours. Generators and associated fuel supplies should be protected by an automatic fire suppression system other than the basement or ground floor level in buildings. Furthermore, if there are storage facilities inside buildings, they should be made of non-combustible materials with a fire rating of not less than one hour and there must be at least one meter of clear space on all sides of the racks.

In order to prevent kitchen fires in high-rise residential structures, user should take below mentioned methods, such as install fire suppression system in the kitchen hood, keep a wet chemical fire extinguisher in the kitchen and use a fire blanket for chip pan fires or wrapping around a person whose clothing is on fire. According to R2 interviewee, always have a qualified person to check heat detectors for proper function of the detectors in case of a kitchen fire.

5 SUGGESTIONS TO IMPROVE THE FIRE SAFETY PERFORMANCE IN SRI LANKAN HIGH-RISE BUILDINGS.

This section mainly focuses on achieving the third objective in the research study. As a result, data collected from semi-structured interviews with industry professionals are used to achieve this objective. It is necessary to identify drawbacks between fire regulations and actual fire safety measures before providing suggestions to improve fire safety performance in high-rise buildings.

5.1 Drawbacks identified between fire regulations and actual fire safety measures in high-rise buildings

It is critical to analyze the drawbacks between fire regulations and actual fire safety measures in order to take corrective actions to address such concerns. If we can overcome those problems, primarily we can save human lives as well as time and money in the event of a fire.

- Building users use a variety of materials to improve the attractiveness of high-rise buildings, but most of them are combustible materials that do not comply with fire resistant ratings.
- Due to the high cost of fire safety systems in the buildings, building users reduce the quantity and use inferior quality equipments that does not comply with fire safety standards.
- According to regulations, fire pumps must be UL listed and consist with positive suction; however, some high-rise buildings, they do not comply with this standard and have negative suction arrangement.
- When a fire breaks out in a high-rise building, people will gather on the basement floor. According to the regulations, smoke extraction systems must be installed in basement floors. However, smoke extraction systems in some high-rise structures are not appropriately designed to extract smoke.
- When gas pipes run through the concealed areas, gas detectors should be installed to detect fires caused by gas leaks. However, in some instances they are not properly placed in those concealed areas.
- As per regulations, there must be a refuge floor at every ten stories in high-rise buildings, but due to architectural concerns, the entrance location is not properly located to enter the refuge area.
- In some high-rise buildings, evacuation path is not clearly marked.
- Sprinkler and a detector are needed in every room in high-rise residential buildings, although some buildings do not install them in required locations due to the high cost of firefighting systems.
- Fire equipment failures, due to lack of proper maintenance.
- Poor management in government apartment buildings.
- Specification provided for each high-rise building is not being followed.

5.2 Suggestions to improve the fire safety performance in high-rise buildings

Since we are living in a rapidly developing technological world, we should update day by day. As a result, when it comes to high-rise building fire safety, we should implement new concepts, practices, and technologies in Sri Lankan high-rise buildings. Therefore, following suggestions are recommended by interviewees in order to improve the fire safety performance in high-rise buildings.

- Introduction of a coordination center for the proper coordination between fire brigade and building fire maintenance department in case of an actual fire.
- It is always advisable to get a service of a qualified fire consultant.
- In order to maintain the quality of firefighting equipments, fire brigade should register the relevant brands or all firefighting systems in the building should comply with NFPA (National Fire Protection Association) or IFE (Institution of Fire Engineers) standards.
- Conduct regular trainings for the maintenance staff.
- Introduction of trained air force squad with helicopters and firefighting equipments.
- Introduction of firefighting drones that can carry four missiles of dry powder to extinguish the fire.
- Aerial firefighting training for firefighters.
- Always adhere to the fire-resistant ratings imposed by fire regulations to minimize the spread of fire in high-rise buildings.
- Qualified person should carry out the regular fire safety inspections in high-rise structures.
- With the connection of the fire brigade, a competent person should conduct regular fire safety awareness programs and building evacuation drills for the occupants.
- Any changes to the elemental structure (additions or alterations) or the nature of the occupancy should be informed to the fire service department and take necessary actions to comply with the changes.

- The necessary fire safety requirements for high-rise buildings should be designed by a qualified designer.
- Ducts and cable tray openings between floors should be closed to prevent fire spread.

5.3 Proposals for proper coordination between fire brigade and building fire maintenance department in case of an actual fire

According to R1interviewee, in the event of a fire, inform the firefighters about water sources within the premises, or if they are insufficient to suppress the fire, inform them about the available water sources around the premises and inform the fire brigade team about the hazardous areas within the premises. R2 interviewee commented that, if there is a proper coordination with the fire brigade, it will be easy to control the fire in a short period of time, as firefighters are familiar with the building fire protection and detection systems. Furthermore, the building maintenance department should coordinate with the fire brigade once in every three months or six months and obtain their assistance in advance. R3 interviewee highlighted that, building fire maintenance department should appoint a single coordination officer to deal with the fire department, as that officer is accountable for any emergency situation in the high-rise structure.

6 CONCLUSION AND RECOMMENDATIONS

This section represents an outline of the research findings. The aim of the study is to identify suggestions to improve the fire safety performance in high-rise buildings in Sri Lanka. This section describes how each research objective is achieved through findings in order to achieve the research aim.

Initially, it is important to identify the factors that contribute to building fires. Failure to consider these factors may lead to under-performance of existing building firefighting systems. Therefore, literature review is mainly focused on achieving this research objective. The identified factors are building design features, human behavior, equipment failures and underperformance of fire regulations, policies and building codes. The second objective is achieved by conducting semi-structured interviews with industry professionals. Most of the professionals stated that fire detection system, fire hydrant system, sprinkler system, fire suppression system, one-way communication system, two-way communication system, portable fire extinguishers, staircase pressurization system and evacuation system are the currently implemented fire safety precautions in high-rise buildings.

The third objective is also achieved by conducting semi-structured interviews with industry professionals. The following suggestions are recommended by most professionals in order to enhance the fire safety performance in high-rise buildings: get a service of a qualified fire consultant for high-rise buildings, register relevant brands by fire brigade in order to maintain the quality of firefighting equipments, maintain proper coordination with the fire brigade and building fire maintenance department, introduce trained air force squad with helicopters and firefighting equipments, conduct regular fire safety awareness programs and evacuation drills for the occupants with the connection of the fire brigade, introduce firefighting drones that can carry four missiles of dry powder to extinguish the fire.

In recommendations, most of the professionals suggest that maintain proper coordination with the fire brigade at all times, use high-quality firefighting equipments recommended by the fire brigade, conduct regular fire evacuation drills and awareness programs with the building occupants and introduce trained air force squad with helicopters and firefighting equipments are the most appropriate suggestions to enhance the fire safety performance in high-rise buildings, which primarily helps to save human lives and property.

There are always limitations in any research paper. This research is limited to fire safety in high-rise buildings in Sri Lanka. As a result, fire safety requirements differ based on the building's height category and the country.

Further research can be focused on following research areas to find solutions to the gaps between fire regulations and actual fire safety measures, examine the differences in fire responses of structural materials and use of innovative firefighting equipments and systems in high-rise buildings.

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