SFT VOL. 61 ISSUE 1, 2023, PP. 54–63

Nalaka Prasanna Jayarathna Liyanapeli[a)*], Amiya Bhaumik[a)], Udayanga Idunil Galappaththi[b)], Deepthi Wickramasinghe[c)]

[a)] *Lincoln University College, Malaysia / Uniwersytet Lincolna w Malezji*
[b)] *Department of Mechanical & Manufacturing Engineering, Faculty of Engineering, University of Ruhuna, Sri Lanka / Dział Inżynierii Mechanicznej i Produkcyjnej, Wydział Inżynierii, Uniwersytet w Ruhunie, Sri Lanka*
[c)] *Department of Zoology and Environment Sciences, University of Colombo / Wydział Zoologii i Nauk o Środowisku, Uniwersytet w Colombo*
[*] *Corresponding author / Autor korespondencyjny: liyanapeli@gmail.com*

Factors Contributing to Increased Building Fire Incidents in Sri Lanka

Czynniki przyczyniające się do zwiększonej liczby pożarów budynków na Sri Lance

ABSTRACT

Purpose: Despite the existence of established fire codes, the frequency of building fires in Sri Lanka has been on the rise in recent years. The primary objective of building codes is to ensure minimum acceptable fire safety standards in buildings, but deviations from the code can increase fire risk factors and exacerbate the severity of fires. This study aims to identify and rank such risk factors in three stages, beginning with design and concluding with maintenance.

Project and Methods: The methodology of this research consists of a qualitative approach, which includes a literature review, a questionnaire-based survey, and semi-structured interviews with fire industry professionals. The questionnaire was developed in a Sri Lankan context following an extensive literature review that included the author's experience. The qualified and experienced panel of fire specialists was asked to rank the prepared questionnaire, which was summarized into twelve risk categories. Though there are few fire risk ranking methods, the relative importance index method was applied in this research as it is simple and easy to use for ranking the risk factors. The results obtained from the five-point Likert scale, where "1" is the least risk level and "5" is the highest risk level, were converted to identify priorities with RII.

Results: In the Sri Lankan context, it was discovered that issues with design and the approval of inaccurate building plans are the first and second major risk factors, respectively, out of the twelve categories identified. Thus, it was evident that deviations made at the design stage are the most significant risk factors, according to the Sri Lankan setting. Most of the mistakes that are made at the design stage cannot be rectified at a later stage under normal conditions, as it could incur huge costs to change the building structures.

Conclusions: The study summarizes twelve factors that contribute to fire-related incidents in Sri Lankan buildings. Among these factors, the survey data shows that incorrect building design and the approval of inaccurate building plans for construction are the primary contributors to the high frequency and severity of fire-related incidents. Despite the availability of comprehensive fire safety regulations in Sri Lanka, the research reveals a significant gap in their implementation, from design to maintenance. These findings stress the importance of incorporating fire and safety management criteria into the building design stage, covering both construction and subsequent maintenance, to prevent fire incidents in Sri Lanka.

Keywords: prescriptive fire codes, fire risk factors, fire risk assessment, fire risk ranking, building fire safety
Type of article: original scientific article

Received: 08.03.2023; Reviewed: 02.05.2023; Accepted: 14.06.2023;
Authors` ORCID IDs: N. Liyanapeli – 0000-0002-5287-1786; A. Bhaumik – 0000-0002-9188-2269; U. Galappaththi – 0000-0002-6646-4831; D. Wickramasinghe – 0000-0001-6026-9552;
Percentage contributon: N. Liyanapeli – 85%; A. Bhaumik – 5%; U. Galappaththi – 5%; D. Wickramasinghe – 5%;
Please cite as: SFT Vol. 61 Issue 1, 2023, pp. 54–63, https://doi.org/10.12845/sft.61.1.2023.3;

ABSTRAKT

Cel: Pomimo istnienia ustalonych przepisów przeciwpożarowych na Sri Lance, częstotliwość występowania tam pożarów budynków rośnie w ostatnich latach. Podstawowym celem przepisów budowlanych jest zapewnienie minimalnych akceptowalnych standardów bezpieczeństwa pożarowego w budynkach, jednak odstępstwa od przepisów mogą zwiększyć czynniki ryzyka pożaru i zaostrzyć dotkliwość pożarów. Niniejsze badanie ma na celu zidentyfikowanie i uszeregowanie tych czynników ryzyka w trzech etapach, począwszy od projektowania, a skończywszy na konserwacji.

Projekt i metody: Metodologia tego badania obejmuje podejście jakościowe, które uwzględnia przegląd literatury, ankietę opartą na kwestionariuszu oraz częściowo ustrukturyzowane wywiady ze specjalistami z branży pożarniczej. Kwestionariusz został opracowany w kontekście Sri Lanki. Wykwalifikowany i doświadczony zespół specjalistów ds. pożarnictwa został poproszony o uszeregowanie przygotowanego kwestionariusza, który został

podsumowany w dwunastu kategoriach ryzyka. Chociaż metod oceny ryzyka pożarowego jest niewiele, w niniejszym badaniu zastosowano metodę wskaźnika względnej istotności. Wyniki uzyskane z pięciostopniowej skali Likerta, gdzie „1" to najmniejszy poziom ryzyka, a „5" to najwyższy poziom ryzyka, zostały przekonwertowane w celu identyfikacji priorytetów z RII.
Wyniki: W kontekście Sri Lanki odkryto, że problemy z projektowaniem i zatwierdzaniem niedokładnych planów budowlanych są odpowiednio pierwszym i drugim głównym czynnikiem ryzyka spośród dwunastu zidentyfikowanych kategorii. W związku z tym było oczywiste, że odchylenia poczynione na etapie projektowania są najważniejszymi czynnikami ryzyka, zgodnie z określonymi warunkami na Sri Lance.
Wnioski: Badanie podsumowuje dwanaście czynników, które przyczyniają się do incydentów związanych z pożarami w budynkach na Sri Lance. Dane ankietowe pokazują, że nieprawidłowy projekt budynku i zatwierdzenie niedokładnych planów budowy są głównymi czynnikami przyczyniającymi się do wysokiej częstotliwości i dotkliwości incydentów związanych z pożarami. Pomimo dostępności kompleksowych przepisów bezpieczeństwa przeciwpożarowego na Sri Lance, badania ujawniają znaczną lukę w ich wdrażaniu, od projektu po konserwację. Wyniki te podkreślają znaczenie uwzględnienia kryteriów zarządzania pożarami i bezpieczeństwem na etapie projektowania budynku, obejmującym zarówno budowę, jak i późniejszą konserwację, aby zapobiegać pożarom na Sri Lance.
Słowa kluczowe: normatywne przepisy przeciwpożarowe, czynniki ryzyka pożarowego, ocena zagrożenia pożarowego, stopnie zagrożenia pożarowego, bezpieczeństwo pożarowe budynków
Typ artykułu: oryginalny artykuł naukowy

Przyjęty: 08.03.2023; Zrecenzowany: 02.05.2023; Zaakceptowany: 14.06.2023;
Identyfikatory ORCID autorów: N. Liyanapeli – 0000-0002-5287-1786; A. Bhaumik – 0000-0002-9188-2269; U. Galappaththi – 0000-0002-6646-4831; D. Wickramasinghe – 0000-0001-6026-9552;
Procentowy wkład merytoryczny: N. Liyanapeli – 85%; A. Bhaumik – 5%; U. Galappaththi – 5%; D. Wickramasinghe – 5%;
Proszę cytować: SFT Vol. 61 Issue 1, 2023, pp. 54–63, https://doi.org/10.12845/sft.61.1.2023.3;

Introduction

More than one million fire deaths resulted from 86.4 million fire incidents between 1993 and 2015, a two-decade period [1], and about 1% of the worldwide GDP is lost annually as a result of all fire hazards [2]. Every year, developed and developing countries experience an average of 3.8 million fires resulting in 44,300 fire fatalities [3]. Between 2010 and 2014, a developed country like the USA reported the largest number of fires (600,000-1,500,000 per year) and the second-highest number of fire deaths (1,000-10,000 per year) in the world [2]. Both the highest number of fire fatalities (10,000–25,000 per year) and the second-highest number of fire incidences (100,000–600,000 per year) have occurred in developing countries like Pakistan and India in the same period [4]. In total, 18,450 fires occurred in 2015, resulting in 1,193 injuries and 17,700 fatalities in India according to a risk survey of 2017. The number of fire occurrences has significantly increased over the past few years, putting human lives in danger and resulting in financial and ecological damages [5]. Sri Lanka is not an exception either.

Fire events have been identified as the second-highest disaster topology in Sri Lanka and the second-highest rate of fire safety non-compliance has been in the Asian region [4]. According to the 2009 National Report on Disaster Risk, Poverty, and Human Development Relationship 2,703 large fires have been reported in Sri Lanka, between 1974 and 2007 [6]. It has been observed that the frequency of building-related fire incidents is increasing in Sri Lanka based on the Fire Service Department statistics [7]. The 113 number of fire incidents which has been reported in 2013 has gradually increased up to 182 fires by 2018 on a yearly basis. Despite showing a decrease in fires to 152 occurrences in 2020, it reveals a distinct and abrupt rising trend from 2013 to 2020. The limitation of commercial activities and people's movements during the peak time of the COVID pandemic may be the reason behind this decline in the year 2020. Parallel to the expansion of the built environment, over the past few years it is evident that there is an increasing trend of fire incidents, especially in densely populated and built-up areas. There are a few factors that can influence the increase in the number of high-rise buildings, such as the development of the urban economy, high population density, increased land prices, etc. [8].

According to the Chamber of the Construction Industry [9], nearly 50 high-rise tower buildings, with more than 20 floors are under construction around Colombo. The above report indicates that just 11 high-rise buildings were built in Colombo city between 2013 and 2017. However, it exhibits dramatic growth trends in the years 2018 to 2020, and in those years, 5, 9, and 42 high-rise structures were added to Colombo city, respectively. People in urban areas are more vulnerable to fire hazards due to large populations involved in business, commercial, and other activities [10]. Based on the above factors, fire safety has taken the stern attention of the public as well as fire experts in Sri Lanka [11].

Today's buildings are becoming larger and more complex. Hence, Van Weyenberge et al. [12] stated that fire safety consideration has been increasingly influenced when designing modern buildings. Presently, building fire safety is mainly achieved through the application of fire safety regulations [13]. Confirming the above, Everton [14] stated that fire safety of a building can be assured to a great extent if it is constructed in compliance with local regulations and laws. One of the main objectives of building fire regulations is to provide the minimum degree of acceptable fire safety levels in buildings [15]. Around the world, two types of fire regulations are available, which are called prescriptive and performance based. However, most of the fire regulations are still prescriptive [12]. The implementation process of prescriptive fire regulation is simple and uncomplicated, as it directly mentions

what users need to comply with [16]. Hence, prescriptive code requirements are deemed to satisfy provisions, and it is considered that fire risks are successfully managed when all standard requirements are met [17].

The Construction Industries Development Authority of Sri Lanka has established a set of prescriptive fire regulations that outline the requirements that users fulfil [18]. These regulations and specifications for buildings and protection systems provide easy design guidelines for a non-complex building to meet the level of safety that is demanded by the society [19]. As it has been mentioned earlier, if fire regulations are fully implemented successfully, buildings should be fire safe. Hence, there should be no reason to increase the number of fire-related incidents, nevertheless, the number of buildings is increasing. However, as the above data indicate that there is a positive correlation between two variables, there should be some reasons behind this. The objective of this research is to find out which of the above factors increases the number of fire-related incidents in Sri Lankan buildings and rank them.

Application of fire safety in different stages of a building

Fire safety precautions need to be considered at each stage of a building's lifetime: planning, construction, occupations, use, maintenance, alteration, extensions, etc. [20]. The above stages of the building can be divided into three stages: the design stage, construction stage, and maintenance stage [21].

Design stage

The fire risk analysis of the buildings should begin from the designing stage [22]. Consequently, the designer must have sound knowledge of fire safety standards and other fire safety requirements. Furthermore, fire safety designers must consider how aging affects various fire safety designs and systems to determine the requirements for operation and maintenance, and the time to replace vital components of the system [23]. During building design, relatively little consideration is given to the operational phase, where it is generally assumed that the reliability of the fire safety system remains constant throughout the building's life cycle [24].

However, if the design is incorrect or does not comply with the existing fire safety regulations, it means the building is not fire safe as the above deviations are adding fire risk factors to the building. The above deviations should be identified during the process of the approval of a building plan. As per the existing building plan approval procedure, relevant authorities review the fire safety requirements of the proposed buildings before they approve them for construction [25]. The Municipal Fire Brigades are the competent authority (authority having jurisdiction) responsible for enforcing applicable fire safety regulations to reduce the risk of building fires [26]. Nonetheless, it has been found that more than 80% of the buildings in Sri Lanka are non-engineered and are profoundly vulnerable to regular hazards [27]. It reveals that there are gaps in the approval procedures of a building plan that can increase the fire risk level of buildings at the design stage. This view is supported by the World Bank Report, which stated that the process of building approval in Sri Lanka is not yet fully comprehensive [27]. Apart from that, Rajanathan [28] urged that Sri Lankan buildings constructed before 1997 should be assessed for fire safety to identify the fire risks associated with these buildings, as they were built before introducing the fire regulations.

Construction Stage

At the construction stage, strict quality control of active and passive fire protection systems is particularly critical to guarantee that they deliver the expected outcomes for a long period of time. The quality of the installed fire protection systems should be examined against the required standards and specifications while ensuring that the vital components of the protection systems have been fixed correctly [23]. Poor standards often adversely impact the ability of the system and the probability of success against the design objectives [29]. The failure of firefighting equipment during a fire can have serious social consequences. Hence, some building codes place responsibility on building authorities to ensure compliance with building regulations throughout the design and construction of new buildings [30]. In addition, if construction, repair, and maintenance work does not meet quality standards, it can lead to extreme cases of premature collapse of buildings, posing a threat to the residents and the firefighters [31].

Structural elements can be provided with fire resistance for either controlling the spread of a fire or preventing structural collapse, or both, depending on the functional requirements for the particular building. The fundamental step in designing buildings for fire safety is to verify that the fire resistance of the structure (or each part of the structure) is greater than the severity of the fire to which the structure is exposed [32]. Due to the above reason, fire resistance in building materials is a growing concern as it is crucial for fire service response and egress of the occupants by protecting the structure. However, it has been noticed in modern buildings increased use of more flammable synthetic material such as plastics and textiles, large quantity of combustible materials and use of goods with unknown composition and uncertain flammable behaviour [33]. Today, many companies produce goods to maximize revenues, regardless of the materials' flammability, by using lighter and thinner materials [34]. Some of them are used to enhance the aesthetics view of the buildings, but most of them are combustible materials that do not meet fire-resistant criteria. Due to the high cost of building fire protection systems, building owners utilize equipment and materials that are of poorer quality and do not adhere to fire safety standards [35]. Therefore, it is necessary to analyse the reaction-to-fire properties of various insulating materials to provide a better understanding of designing a fire-safe structure [36].

Maintenance Stage

A common misunderstanding among building owners is, that if the relevant authorities sign off the building, it means the building is fully fire-safe [37]. According to Browne [38] various elements of a building will change throughout its working life

beginning as soon as it is completed. In addition, the building may be weakened due to aging [20], [31]. The problem is that the extension of fire systems, modification of fire protection systems, and fire detection systems are not changed accordingly with these changes or modifications [39], [40]. During the lifetime of a building, any changes to building layouts, use of the building, or alterations will need to be assessed to identify their effect on the overall fire safety strategy. Likewise, it is required to change the management systems and procedures together with the building changes. A crucial part of the fire safety management system is the servicing and maintenance of the fire protection systems on time. Fire protection systems may not provide designated functions unless they are regularly inspected or maintained [25].

Maintaining good housekeeping is an important strategy for fire safety management. It reduces the likelihood of fires, decreases the potential growth rate and size of fires, and ensures that fire protection systems in buildings operate as intended in the event of a fire. There are two main aspects of housekeeping: reducing the likelihood of a fire or initiating it whilst protecting the escape routes [23]. Even in a situation where the structural elements are of low combustibility, stored items can provide the fuel for fires to develop into large fires [41]. Similarly to that, employee awareness and training play a significant role to inhibit fire growth to serious levels. There is always a risk of fires developing to a dangerous level if not successfully controlled by the staff at the initial stages [42]. "It is well recognized that occupants extinguish many small fires before they can grow" [43]. The possibility of extinguishing fires by staff members would depend on their training and the amount of firefighting equipment they possess [44]. Similarly, having a correct emergency response plan is an important factor in keeping building occupants safe from hazards such as a fire, as it reduces evacuation time, mitigates the impact of a fire, and prevents death and injury [45]. The nature of emergencies is very complex and dynamic. Hence, it should be precious to minimize the possible impact of a fire [46].

The possibility of a new fire hazard has emerged with the increase of flammable and combustible building contents, including furniture and furnishing materials. Building fire safety is vital, especially when the contents of the buildings increase the fire loads. As a result, the materials involved with building contents are crucial for meeting the requirements for fire safety [47]. However, to get a comprehensive understanding of how fire affects a building material, it is necessary to study the properties of the material used that are affected by high temperatures [48]. As an example, furniture fires currently account for 2% of all home fires in the USA, but they account for a much greater percentage (19%) of all fire fatalities [47]. The majority of residential and commercial furniture manufactured in the United States, according to estimates from the furniture industry and state agencies, will not include flame retardants in the foam as of January 2020 [49]. Determining the fire risk of a building's contents and furnishings both during construction and after occupancy should therefore be a component of the proper fire management systems.

Fire Risk Assessment

Fire safety in buildings can be achieved by improving passive fire safety in buildings, installing necessary active fire safety systems, and establishing necessary fire safety management systems in line with regulatory requirements [51]. Fire safety management is the application of guidelines, tools, standards, information, and practices to the analysis, assessment, and control of fire safety by building managers [52]. As it has been mentioned earlier, it is believed that the levels of fire safety of the building are acceptable if all the regulatory requirements have been implemented in prescriptive-type fire regulations [12]. This is the concept that is intended to develop a tool to assess the risk levels of Sri Lankan buildings as it can easily identify the deviations against the prescriptive regulations.

"A fire risk assessment has always been a challenging task" [53]. During the assessment process of a fire risk the likelihood of fires and their consequences is measured. To assess the risk levels, it is required to obtain meaningful data from different sources, including objective, and subjective data together with input from interested or affected stakeholders [54]. The assessment process of a fire risk involves the application of the established risk criteria to decide the level of a fire risk. Although numerous building fire safety assessment tools have been developed over the past four decades, none of them adequately consider building design features and their related impacts as key performance factors [55]. However, fire risk analysis can be performed in different ways depending on the purpose and scope of the analysis. The methodologies used to analyze fire risk may also vary depending on the quantity, quality, and detail of the data for a given purpose [54].

Various factors can affect the fire risk level of a building. All the factors should not be considered as equally important. Therefore, rating fire risk factors gives an initial idea about the weighting method of the risk factors [56]. The Fire Safety ranking system is one of the risk assessment processes which evaluates the performance of various fire safety attributes of buildings and quantifies the fire risk level [57]. Several methods are used to rank the fire safety factors of the buildings. Some of them are direct point allocation, paired comparison (multiple regression models, explicit trade-offs), and equal unit weighting [58]. In addition to the above, some other methods are also available, such as the fuzzy synthetic evaluation system for computing the fire risk ranking of buildings [59].

Methodology

The methodology of this research consists of a qualitative approach, which includes an extensive literature review and questionnaire-based survey, and semi-structured interviews with fire industry professionals. The qualitative risk assessment can be developed by allocating points or scores to answers in a questionnaire by giving numerical values to the scores increasing with the risk level [60]. The data evaluation can be done by using the relative importance index (RII) technique as it can be used to rank attributes. In this research, judgments were obtained from fire experts, to rank the fire risk factors for the analysis of the

objective and the determination of the weightage of risk factors. The results obtained from the five-point Likert scale "1" is the least risk level and "5" is the highest risk level were converted to identify priorities with RII. Below equation was used to calculate the relative importance index:

$$RII = \sum W / (A * N) \quad (1)$$

where:

RII – relative importance index;
W – weighting given to each factor by the respondents (ranging from 1 to 5);
A – highest weight (i.e. 5 in this case) and
N – total number of respondents [61].

The purposive sampling technique was selected which is a non-probability sampling, as this sampling technique is most suitable for interviewees, and also it is a sampling technique convenient for survey respondents [62]. Current knowledge in this area was explored through searching scientific journals and fire safety codes and standards, including the CIDA fire regulations, International Fire Code, British, and European fire standards. These factors were summarized in a questionnaire to derive the relative importance of the selected fire risk factors, and thus determine their relative weights. This was achieved through the relative important index (RII).

Questionnaire design, administration, and analysis

The primary-level data was gathered from the literature review together with the author's observations in the field of fire to build up the questionnaire. The questionnaire and semi-structured interviews were used to gather the data and a five-point Likert scale model was used to rank the identified problematic issues. To achieve the above objective, interviews were also carried out with selected experts. Purposive non-probability sampling was chosen because there were no probabilities associated with population units, and the selection was based on the judgment of the researcher.

Only corporate and graduate members of the Institution of Fire Engineers in Sri Lanka were selected for this study in order to assure the validity of the results. This was done in accordance with the clear requirements of the Fire Service Department, which state that all building plans must be approved by members of the Sri Lanka Institution of Fire Engineers. It was found that there are only 9 corporate members and 16 graduate members who are actively involved with fire-related activities at present in Sri Lanka. Out of 9 active corporate members, 6 members, and out of 16 graduate members, 10 members were purposely selected from the below listed key specialized areas. The sample size is above the 50% of the total population. All of them were qualified through the fire engineering examinations conducted by the institution of fire engineers in the U.K and have more than 15 years of experience in the field of fire engineering and firefighting. These are:

- members who are engaged in fire service operations,
- members who are working as fire consultants,
- members who are engaged in fire systems designs and installations.

Selected experts were asked to rank the risk factors which could increase the risk level of the Sri Lankan buildings assuming that the possibility of the fires is developed into the fully developed levels. The fire risk factors which could contribute to the increase in the number of building fires in Sri Lanka could be added to buildings from the design stage to the maintenance stages.

At the design stage, deviations could happen in two ways. The first one is the incorrect building design and the second one is the approval of the incorrect building plans by the relevant authorities. Even though the building is incorrectly designed by the architects, constructing the incorrectly designed building can be avoided at the building plan-approving stage. However, it is evident in many ways that there is a large amount of fire safety deviations in the existing buildings. This could also be the result of two main factors. The first one is the lack of subject knowledge among fire service staff, especially outside the Colombo city area. The second reason is approving the incorrect building plans under various influences. Based on the above circumstances, below fire risk factors could be added to the building before construction:

1. The first factor is an incorrect building design.
   Examples: Lack of exits, exceeding travel distances, and not complying with compartmentation requirements. No fire lobbies & smoke lobbies, incorrect placement of hose reels, landing valves, etc.
2. The second factor is approving the incorrect building plans.
   Examples: Local authorities do not have enough subject knowledge to check the incorrect design. Noncompliance building plans approved under various influences, etc.

Three factors that may have an impact on the fire protection system's appropriate operation were determined based on the literature review and the author's observations:

1. Incorrect or substandard materials/equipment/components used for fire safety systems.
   Examples: Not using certified products for protection and detection systems, low quality of components and equipment, etc.
2. Equipment, components, and the material do not comply with the required specifications and standards.
   Examples: Low output of fire pumps, fire pump performance curves not complying with fire pump requirements, pipes and cables not complying with local specifications, etc.
3. Incorrect fixing of fire safety systems.
   Examples: Mounting of detectors exceeding the maximum height, sprinkler heads close to beams, common suction lines for pumps, mounting of detectors close to the walls, hydrants are very close to external walls, etc.

Some of the risk factors that are adding to the building at the maintenance stage of the buildings are due to occupying, aging, lack of maintenance, poor management system, etc. All the above functions are part of the fire safety management system. However, as fire safety management comprises a wider range of topics, it was summarized into seven areas that were determined to be more predominant in Sri Lankan buildings based on the aforementioned literature analysis, expert interviews, and the author's own experiences.

The main identified areas are as below:

1. Lack of awareness.
   Examples: Not having fire safety-related awareness, no idea about the fire regulations and standard requirements, service requirements, etc.
2. Poor housekeeping and practices.
   Examples: Not maintaining good housekeeping, dust and garbage accumulation, unnecessarily increasing the fire load, fire exits and pathways blocked, etc.
3. Lack of training in firefighting and emergency response.
   Examples: Not enough people trained in terms of fire safety, no required skill level of fire wardens, no emergency response plans and no practice, etc.
4. Not having adequate fire safety systems.
   Examples: no hose reels, detection systems, hydrants, sprinkler systems, etc. even though they are required by the regulations.
5. Poor maintenance of the fire safety system.
   Examples: Systems and components are not in service or poorly functioning, not servicing, maintenance, and repairing according to the standard requirements, etc.
6. Lack of fire safety management system.
   Examples: no responsible person, no fire safety inspection procedures, no authority to take corrective actions, poor communication between relevant authorities, changes to passive fire protection systems without corrective actions, etc.
7. Not having an adequate emergency response plan.
   Examples: no pre-plans and emergency response plans, no rehearsals on emergency response, poor plans, or not updated regularly.

Participants received a thorough explanation of all the above-mentioned risk factors, as well as examples that helped them understand each question. Participants were also requested to share their opinions and solutions for resolving each issue pertinent to the Sri Lankan context.

The aforementioned problems are significant contributors to the rise in fire safety-related events in Sri Lankan buildings at various phases of their lifespans. The identification and ranking of the above key factors are one of the main objectives of this study. By identifying the most important risk factors and their relative risk levels, it will be easier for the relevant authorities to take the necessary corrective action to reduce the frequency of fire-related incidents in Sri Lankan buildings.

Result and discussion

This research aims to investigate the fire risk factors that may have led to an increase in building fires and their severity in Sri Lanka during the past few years. These risk factors which are added to the building in three different stages of buildings and summarized factors were addressed to a panel of experts. Finally, the risk factors were quantified based on the expert responses.

Table 1. Finalized risk factors and risk ranking

No.	Fire Risk Factors	IRR	Rank
	Design Stage		
1	Problems associated with the building plan design stage	0.912	1
2	Problems associated with the building plan approval stage	0.875	2
3	Poor maintenance of the fire safety system	0.862	3
4	Lack of fire safety management system	0.862	3
5	Incorrect or substandard materials/equipment/component used for fire safety systems	0.85	4
6	No adequate fire safety systems	0.85	4
7	Poor housekeeping and practices	0.837	5
8	No adequate emergency response plans	0.837	5
9	No training in firefighting and emergency response	0.825	6
10	Equipment, component, and the material do not comply with the required specifications	0.8	7
11	No awareness	0.787	8
12	Incorrect fixing of fire safety systems	0.787	8

Source: Own elaboration.

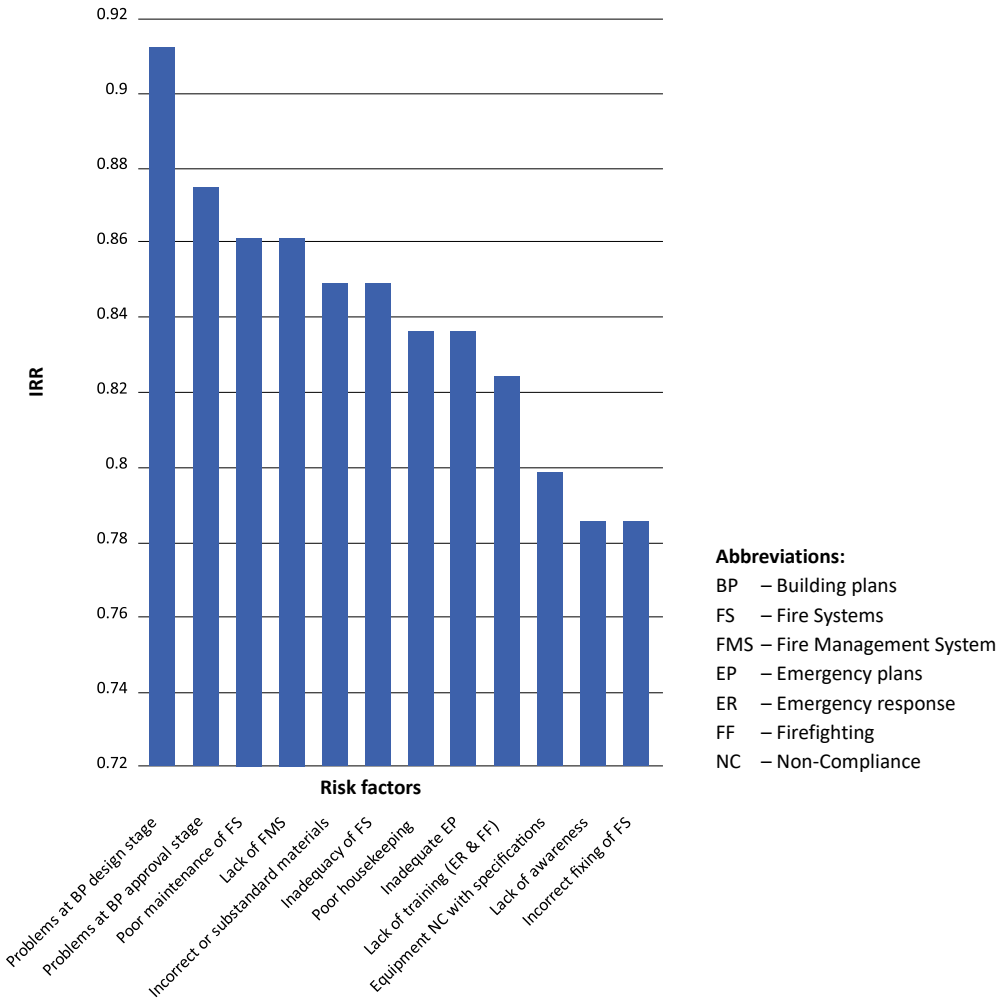

Figure 1. Ranking the fire risks factors
Source: Own elaboration.

The findings of the twelve-factor analysis highlight the crucial role played by the building plan design stage in ensuring fire safety in Sri Lankan buildings. The high weightage given to "Problems associated with the building plan design stage"and "Problems associated with the building plan approval stage" clearly indicates the need for greater attention to be given to these stages of the building process to ensure that fire safety is adequately addressed. The fact that mistakes made during the design stage cannot be easily rectified at a later stage underscores the importance of ensuring that proper fire safety measures are incorporated into the building plan from the outset. Failure to do so can result in significant costs and risks associated with retrofitting fire safety measures to an already constructed building. Non-compliance with passive fire protection systems is also identified as a significant risk factor that cannot be offset by the functioning of other safety systems. The example of having one staircase for a medium or high-rise building where two are required highlights the importance of complying with the appropriate safety standards to ensure the safety of occupants in the event of a fire.

The approval of incorrect building plans for construction under various influences and the lack of subject expertise on the part of the building plan-approving authority are the reasons that "problems associated with the building plan approval stage" are ranked as the second-highest risk factor. Due to a lack of qualified professionals to approve the building plans, there is a considerable gap in building plan approval criteria outside of the Colombo major city region. Additionally, the building plan approval stage needs to be strengthened because this is where errors made by the design team may be fixed. Once the building is constructed, structural alterations cannot normally be changed back.

Based on the analysis conducted, it has been found that the third highest risk factor associated with building fire safety is the "No fire safety management system" along with its sub-factor i.e. "Poor maintenance of fire safety systems". The lack of a proper management system can lead to several key sub-factors that can compromise fire safety, such as the absence of responsible individuals, insufficient allocation of financial and human resources, inadequate inspection procedures, no authority to take corrective actions, poor communication between relevant authorities, absence of work control procedures, and unauthorized changes to passive fire protection systems. While "Poor maintenance of fire safety systems" is a sub-factor of "No fire safety management system", all other factors associated with maintenance are

also considered sub-sections of the lack of a management system. To accurately identify these sub-factors, responders were asked to evaluate each factor individually, emphasizing the critical areas where a lack of management could lead to compromised fire safety. Addressing the lack of a proper management system is crucial to ensure that fire safety is maintained in buildings and taking corrective actions in this regard is imperative.

In the analysis conducted, it was found that the 4th risk factor associated with building fire safety is the use of incorrect or substandard materials/equipment/components for fire safety systems and inadequate fire safety systems. The quality of fire safety components is critical to ensure that they function properly in emergency situations. Moreover, not having adequate fire safety systems is a common issue in some buildings in Sri Lanka. Despite the requirements set by fire regulations, many buildings still lack the necessary detection and protection systems, which may be attributed to the high-ranking risk factors of problems during the building plan design and approval stages. Therefore, it is important to address these key risk factors to ensure that fire safety systems are properly installed and maintained in buildings.

The fifth risk factor identified in the analysis was attributed to poor housekeeping procedures and a lack of effective emergency response strategies. Poor housekeeping standards can contribute to the ignition and rapid spread of fires within buildings, increasing the risk of harm to occupants and damage to property. Effective emergency response plans and strategies are essential for minimizing the impact of fires and protecting lives and property. However, despite the importance of emergency preparedness, many building owners in Sri Lanka appear to place greater emphasis on fire protection measures rather than on developing comprehensive emergency response plans.

The sixth-ranked risk factor is the "No training on firefighting and emergency response". Providing the necessary training for staff is crucial, as evidence shows that fires can be extinguished at an early stage before they become serious. The seventh risk factor is the use of equipment, components, and materials that do not comply with the required specifications. Some building owners still install fire protection systems that do not meet the standards. Due to the high cost, building owners often choose equipment or components that do not meet the required specifications of the protection systems. Lastly, the eighth-ranked risk factor is the incorrect installation of fire safety systems and lack of awareness. These factors receive less attention as they can be corrected at a reasonable cost at any time. Despite there being 12 risk factors to be analyzed, only eight of the components received rankings since some factors were given equal weighting based on professional judgment.

Conclusion

The study summarizes twelve factors that contribute to fire related incidents in Sri Lankan buildings. Among these factors, the survey data shows that incorrect building design and approval of inaccurate building plans for construction are the primary contributors to the high frequency and severity of fire-related incidents. The study also highlights a lack of proper management system and fire safety system maintenance as the third risk factor. Despite the availability of comprehensive fire safety regulations in Sri Lanka, the research reveals a significant gap in their implementation from design to maintenance. These findings stress the importance of incorporating fire and safety management criteria in the building design stage, covering both construction and subsequent maintenance, to prevent fire incidents in Sri Lanka.

Literature

[1] Brushlinsky N.N., Ahrens M., Sokolov S.V., Wagner P., *World fire statistics 2017*, CTIF, International Association of Fire and Rescue Services, 2017.

[2] Kodur V.R., Kumar P., Rafi M.M., *Fire hazard in buildings: review, assessment and strategies for improving fire safety*, "PSU Research Review" 2019, September, https:/doi.org/10.1108/PRR-12-2018-0033.

[3] Wagner N.B.A.S., "World Fire Statistics" 2018, Vol. 23.

[4] Rathnayake I., Sridarran P., Abeynayake M.D.T.E., *Factors contributing to Building Fire Incidents: A review, Proceedings International Conference on Industrial Engineering and Operations Management*, UAE, March, 2020.

[5] Rathnayake R.M.D.I.M., Sridarran P., Abeynayake M.D.T.E., *Factors contributing to building fire incidents: A review, Proceedings International Conference on Industrial Engineering and Operations Management*, UAE, March, 2020, pp. 123–134.

[6] Rathnayake R.M.D.I.M., Sridarran P., Abeynayake M.D.T.E., *Fire risk of apparel manufacturing buildings in Sri Lanka*, "Journal of Facilities Management" 2022, vol. 20, no. 1, pp. 59–78, https:/doi.org/10.1108/JFM-11-2020-0082.

[7] Fire Service Department Internal Report, 2020.

[8] Lau C.K., Lai K.K., Lee Y.P., Du J., *Fire risk assessment with scoring system, using the support vector machine approach*, "Fire Safety Journal" 2015, vol. 78, pp. 188–195, https:/doi.org/10.1016/j.firesaf.2015.10.003.

[9] *Are we sitting on a Time Bomb with Fire Risk in Buildings?*, The Chamber of Construction Industry Sri Lanka, "Daily News" 2019, January, https://www.dailynews.lk/2019/01/21/business/174840/are-we-sitting-time-bomb-fire-risk-buildings [dostęp: 08.03.2023].

[10] Ilyas U., *Assessment of Fire Safety Management of High Rise Buildings in Lahore*, "International Journal of Emerging Technologies in Learning" 2021, vol. 12(1), 241–246.

[11] Aluthwala A.D., Wickramarathne D.K.S., Wijeratne R.K.M.J.B, Jayasinghe M.T.R., *Fire Safety in High Rise Buildings Fire Safety in High Rise Buildings*, "Annual Transactions of IESL" 2011, no. April, pp. 37–41.

[12] Van Weyenberge B., Deckers X., Caspeele R., Merci B., *Development of an Integrated Risk Assessment Method to Quantify the Life Safety Risk in Buildings in Case of Fire*, "Fire Technolnology" 2019, vol. 55, no. 4, pp. 1211–1242, https:/doi.org/10.1007/s10694-018-0763-6.

[13] Kodur V., Kumar P., Rafi M.M., *Fire hazard in buildings: review , assessment and strategies for improving fire safety*, "PSU Research Review 2020", vol. 4, no. 1, pp. 1–23, https:/doi.org/10.1108/PRR-12-2018-0033.

[14] Everton A., *Local authority*, "Fire prevention and Fire Engineering Journal" 2006, vol. 65, pp. 21–23.

[15] Paper C., Carl U., Independent J., Johansson U.C., *An Approach to Quantify the Current Level of Safety Achieved by the Building Code*, Proceedings of the Society of Fire Safety International Fire Safety Engineering Conference 'Raising the Bar', no. March 2011.

[16] Lundin J., *Safety in Case of Fire – The Effect of Changing Regulations Johan Lundin Department of Fire Safety Engineering*, 2005.

[17] Sanctis D., Research Collection, 2015.

[18] CIDA, CIDA Fire Regulation, 2018.

[19] Johansson U.C., *Quantifying Risk for Deemed-to-Satisfy Apartment Buildings*, p. 142, Lund 2010.

[20] Cox P., *Risk Venture. Fire safety strategies for building*, "Fire Prevention and Fire Engineers Journal" 2005, vol. 64, pp. 26–27.

[21] Xiuyu L.I.U., Hao Z., Qingming Z.H.U, 2012 International Symposium on Safety Science and Technology Factor analysis of high-rise building fires reasons and fire protection measures, vol. 45, pp. 643–648, 2012, https:/doi.org/10.1016/j.proeng.2012.08.216.

[22] Marchant E., *Fire risk assessment*, "Fire Engineers Journal" 1999, vol. 59(201).

[23] BSI standard publication, *Code of practice for fire safety in the design, management, and use of buildings*, 2008.

[24] Tan S., Weinert D., Joseph P., Moinuddin K., *Sensitivity and uncertainty analyses of human and organizational risks in fire safety systems for high-rise residential buildings with probabilistic t-h-o-risk methodology*, "Applied Sciences", vol. 11, no. 6, 2021, doi: 10.3390/app11062590.

[25] Liyanapeli N., *Assessment of fire risk levels of industrial buildings in biyagama export processing zone area*, Master Thesis, Department of Building Economics University of Moratuwa Sri Lanka, January, 2017.

[26] Madaio M. et al., *Firebird Predicting Fire Risk and Prioritizing Fire Inspections in Atlanta*, ACM KDD Conference, pp. 185–194, 2016, https:/doi.org/10.1145/2939672.2939682.

[27] Managing Risks for a Safer Built Environment Building Regulatory Capacity Assessment Building Regulation for Resilience Program, no. August, 2020.

[28] Rajanathan S., *Inspection System for Old Public Buildings and Apartments in Colombo Municipal Areas*, NBRO Symposium 2015 "Innovations Resilient Environment", 2015.

[29] Bird S.N., Bouchlaghem N.M., Glockling J., Yeomans S.G., *Decision Problem Structuring Method For The Specification And Selection Of Active Fire Protection Systems*, 7th International Conference on Innovation in Architecture, Engineering and Construction, 2012, [dostęp: 08.03.2023], https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/15903.

[30] Xiao X., Marchant E., Griffith A., *The macro quality assurance system for fire safety engineering*, "Fire Technology" 1994, vol. 30, no. 3, pp. 366–373, https:/doi.org/10.1007/BF01038071.

[31] Ellicott G., *Past Experience*, "Fire Prevention and Fire Engineers Journal" 2006, vol. 66, p. 25.

[32] Gross J.L., Phan L.T., "Summary of best practice guidelines for structural fire resistance design of concrete and steel buildings, Structed Congress 2010, vol. 119, no. 2007, pp. 2369–2379, https:/doi.org/10.1061/41130(369)215.

[33] Mullins-Jaime C., Smith T.D., *Nanotechnology in Residential Building Materials for Better Fire Protection and Life Safety Outcomes*, "Fire" 2022, vol. 5, no. 6, pp. 1–12, https:/doi.org/10.3390/fire5060174.

[34] Hiemstra H., *Influence of Building Structure and Building Content on Residential Fires*, Master Thesis, Lund 2016.

[35] Perera L., Allis C., *Fire Safety Performance of High-rise buildings in Sri Lanka*, The SLIIT International Conference on Engineering and Technology, no. March, 2022, pp. 69–78, 2022, https:/doi.org/10.54389/onlz8762.

[36] Hossain M.D. et al., *Fire Behaviour of Insulation Panels Commonly Used in High-Rise Buildings*, "Fire" 2022, vol. 5, no. 3, https:/doi.org/10.3390/fire5030081.

[37] Oliver A., *Building momentum*, "Fire Risk Manag. Int. J. Fire Prof." 2010, vol. 71, pp. 34–35.

[38] Brown P., *Safety design*, "Fire Engineers Journal" 2003, vol. 57, pp. 28–31.

[39] Connolly R., *The quantifications of the risk of fire spread within the building*, "Fire Engineers Journal" 1999, vol. 59–201.

[40] Williams B., *Light Maintenance*, "Fire Prevention and Fire Engineers Journal" 2006, vol. 66, pp. 14–16.

[41] Babrauskas V., *Performance-Based Building Codes: What Will Happen To the Levels of Safety*?, "Fire Science and Technology" 1998.

[42] Glockling J., *Business and property protection*, "Fire Risk Manag. Int. J. Fire Prof." 2012, vol. 73, pp. 18–19.

[43] Winkworth G., *The building fire performance evaluation methodology*, "Fire Engineers Journal, vol. 58–195, 1999.

[44] Johansson H., *Decision Making in Fire Risk Management*, Lund 2001, [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.202.2345&rep=rep1&type=pdf

[45] Camelia A., *Reliability Evaluation of Emergency Reponse Plan Design in Buildings of Sriwijaya University 2019*, Proceedings of the 2nd Sriwijaya International Conference of Public Health (SICPH 2019), vol. 25, no. Sicph 2019, pp. 86–94, 2020.

[46] Bitencourt K., Durão F., Mendonça M., EmergencyFire: *An ontology for fire emergency situations*, WebMedia 2015 - Proc. 21st Brazilian Symp. Multimed. Web, pp. 73–76, 2015, https:/doi.org/10.1145/2820426.282045.

[47] Popescu C.M., Pfriem A., *Treatments and modification to improve the reaction to fire of wood and wood based*

products – An overview, "Fire Mater" 2020, vol. 44, no. 1, pp. 100–111, https:/doi.org/10.1002/fam.2779.

[48] Delegou E.T. et al., *The Effect of Fire on Building Materials: The Case-Study of the Varnakova Monastery Cells in Central Greece*, "Heritage" 2019, vol. 2, no. 2, pp. 1233–1259, https:/doi.org/10.3390/heritage2020080.

[49] Charbonnet J.A., Weber R., Blum A., *Flammability standards for furniture, building insulation and electronics: Benefit and risk*, "Emerging Contaminants" 2020, vol. 6, pp. 432–441, doi: 10.1016/j.emcon.2020.05.002.

[50] Cvetković V.M., Dragašević A., Protić D., Janković B., Nikolić N., Milošević P., *Fire Safety Behavior Model for Residential Buildings: Implications for Disaster Risk Reduction*, "SSRN Electron. J." 2021, doi: 10.2139/ssrn.3974738.

[51] Kaseem A.M., Yatim Y.M., Yusoff W., Mahmood W., *Adequate Fire Safety Training for the Occupants Knowledge and Awareness of Fire Safety*, "International Journal of Academic Research in Progressive Education and Development" 2021, 10(2226-6348), pp. 13–24.

[52] Danzi E., Fiorentini L., Marmo L., *FLAME: A Parametric Fire Risk Assessment Method Supporting Performance Based Approaches*, "Fire Technology" 2021, 57, pp. 721–765, https:/doi.org/10.1007/s10694-020-01014-9.

[53] Watts J.M. JR., Hall J.R. JR., *Introduction to fire risk analysis*, *SFPE handbook of fire protection engineering*, Springer, New York 2016.

[54] Park H., *Development of a Holistic Approach To Integrate Fire Safety Performance With Building Design*, PhD Propos., p. 141, Worcester 2014.

[55] Kit C., Keung K., Pui Y., Du J., *Fire risk assessment with scoring system, using the support vector machine approach*, "Fire Safety Journal" 2015, vol. 78, pp. 188–195, https:/doi.org/10.1016/j.firesaf.2015.10.003.

[56] Hassanain M.A., Hafeez M.A., Sanni-Anibire M.O., *A ranking system for fire safety performance of student housing facilities*, "Safety Science" 2017, vol. 92, pp. 116–127, 2017, https:/doi.org/10.1016/j.ssci.2016.10.002.

[57] Zhao C.M., Lo S.M., Lu J.A., Fang Z., *A simulation approach for ranking of fire safety attributes of existing buildings*, "Fire Safety Journal" 2004, vol. 39, no. 7, pp. 557–579, https:/doi.org/10.1016/j.firesaf.2004.06.001.

[58] Liu M., Lo S.M., Hu B.Q., Zhao C.M., *On the use of fuzzy synthetic evaluation and optimal classification for computing fire risk ranking of buildings*, "Neural Computing and Applications" 2009, vol. 18, no. 6, pp. 643–652, doi: 10.1007/s00521-009-0244-4.

[59] Ramachandran G., *Fire safety management and risk assessment*, "Facilities" 1999, vol. 17, pp. 363–377, https:/doi.org/10.1108/02632779910278782.

[60] Egemen M., "Building Construction Clients' Design Consultant and Contractor Selection Criteria Versus Post-Occupancy Satisfaction Levels, "SAGE Open" 2022, https:/doi.org/10.1177/21582440221089968.

[61] Rowley J., "Designing and using research questionnaires, "Management Research. Review" 2014, vol. 37, no. 3, pp. 308–330, https:/doi.org/10.1108/MRR-02-2013-0027.

AMIYA BHAUMIK, PH.D., PROFESSOR – President of Lincoln University College Malaysia Amiya Bhaumik, the Founder and Vice-Chancellor of Lincoln University College. He is purely from the field of education. Since 1999 he is Executive Vice President of the International Education Consulting Group, St. Louis, USA. He was a research fellow of UNESCO, Paris. He served as a Professor of Business Administration at the University of Lucknow, India, and at the University of Malaya and many other places.

NALAKA PRASANNA JAYARATHNA LIYANAPELI, M.SC. – he works as a manager of the environment, health and safety, and compliance in a multinational company in Sri Lanka. He is a corporate member of the Institution of Fire Engineers in UK and the immediate past president of the Institution of Fire Engineers in Sri Lanka. He has more than 25 years of experience in fire safety and fire engineering in various fire services in reputed companies in Sri Lanka. He studied pertinent to Environment Management and Occupational Health & Safety at the University of Colombo, and the University of Moratuwa in Sri Lanka. Currently, he is a Ph.D. candidate in Industrial Management at Lincoln University College, Malaysia. His research involves issues related to fire risk assessments and building fire safety in Sri Lanka. He is the author of a few publications relevant to the environment, health, safety and building fire safety.

UDAYANGA I.K. GALAPPATHTHI, PH.D. – he is currently serving as a resource person for the faculty of engineering, University of Ruhuna, Sri Lanka. He completed a bachelor's degree (Hons. in Mechanical and Manufacturing Engineering) at the University of Ruhuna and a Ph.D. at Glasgow Caledonian University. He has more than eighteen years of experience in different areas of engineering disciplines including building service engineering. He serves in many local and international expert committees for the national development in Sri Lanka.

DEEPTHI WICKRAMASINGHE, PROFESSOR – she is currently serving as a professor in the Department of Zoology and Environment Sciences, University of Colombo, Sri Lanka. She obtained a bachelor's degree (Hons. in Environmental Science) and M.Sc. in Environmental Science at the University of Colombo. She studied at Dalhousie University, Canada, and the University of Colombo for her Ph.D. in Conservation Biology. She has more than twenty five years of experience in environmental conservation, community development, and youth empowerment projects. She held many key positions in local scientific organizations and was the President of the Institute of Biology in 2010. Her interests include water (both inland and coastal habitats), climate change and disaster risk reduction, nature-based solutions, sustainable development, and gender. She serves in many local and international expert committees in these areas.