Megaron, Vol. 19, No. 04, pp. 462–478, December 2024

Megaron
https://megaron.yildiz.edu.tr - https://megaronjournal.com
DOI: https://doi.org/10.14744/megaron.2024.73669

MEGARON

Article

Analysis of user-related risks in fire-safe building design

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ARTICLE INFO

Article history
Received: 17 April 2024
Revised: 11 November 2024
Accepted: 11 November 2024

Key words:
Fire evacuation, fire safety, human behavior in fire, risk assessment.

ABSTRACT

Fire safety encompasses protection from fire, limitation of the spread of fire and smoke, fire suppression, and the provision of rapid and safe means of escape. Human behavior plays a crucial role in ensuring an effective evacuation. It is well-established that users' physiology, psychology, and behaviors during emergencies impact building usage conditions. Fire safety in buildings may not be fully achieved solely through meeting fire-safe design regulations and legal requirements; instead, a comprehensive approach that offers solutions tailored to user characteristics is necessary. Therefore, adapting fire safety measures in buildings to align with building- and user-specific attributes is deemed essential for facilitating timely and safe evacuations.

In this study, risks associated with different users in direct interaction with the building's function are identified and analyzed within the context of fire-safe building design. User-related risks are determined through a systematic literature review and meta-analysis and are evaluated in conjunction with fire incidents that occurred previously. According to the analysis results, the identified user-related risks for fire-safe building design are categorized into three groups: Risks associated with individual, social, and situational characteristics. Determining the risks associated with users who need to be evacuated during building fires is considered crucial for comprehending user characteristics, response times, and behavior patterns, as well as for developing effective evacuation strategies. It is argued that preventive measures addressing these risks could help avert or minimize casualties during fires.

Cite this article as: Yıldırım, H. S., Avlar, E. (2024). Analysis of user-related risks in fire-safe building design. Megaron, 19(3), 462-478.

INTRODUCTION

Fire safety implies protection from fire, limitation of the spread of fire and smoke, fire suppression, and the provision of rapid and safe means of escape. Safe evacuation, on the other hand, is the most critical phase of a building's fire safety procedures (Shai & Lupinacci, 2003). However, some major fires experienced in the past have proven that safe evacuation from a burning building is not always possible.

Since the mid-1960s, there has been significant progress worldwide in reducing fatalities caused by fires. This progress is generally attributed to changes eventuated in the lifestyle of people, including the widespread use of fire detection and suppression systems, the introduction of new regulations in laws and standards, and increased public awareness (Shai & Lupinacci, 2003). However, it can be argued that user-related risks in fires are still continued to be overlooked more often than not, even today. Past fire

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incidents and related studies have shown that, up until now, user-related risks had been incorporated into fire safety measures in buildings only to a limited extent.

As of today, knowledge about users' responses during a fire and their evacuation performance is very limited. Therefore, to fully address fire safety in buildings, apprehending why some major fires result in a high number of casualties, while others cause minimal loss of life, is crucial. It is evident that understanding the user is a vital aspect in studies aimed at preventing or reducing casualties during fires and identifying the critical factors that influence evacuation performance and fire response (Kobes et al, 2010).

Studies conducted after 1980 on users who got caught in the building during a fire primarily focused on the evacuation of users with physical limitations. During this period, computer models developed for the evacuation of users have provided more realistic forecasts of how occupants might move during an evacuation. Following these advancements, results obtained from these computerized evacuation models have been reflected in fire regulations worldwide as quantified evacuation times. A successful evacuation can significantly ensure user safety. To achieve this, actions designed to guide users in an orderly, rapid, and safe evacuation must be executed in a timely and appropriate manner (Balboa et al, 2020; Rendón Rozo et al, 2019). Emergency evacuation plans prepared currently are generally based on static evacuation routes (Fu et al, 2019). However, during an emergency situation in which users struggle to identify risks, comprehend them fully, and decide what actions to take, existing evacuation strategies may not provide adequate safety (Jeon et al, 2011). In particular, the risks that arise during a fire in multi-functional buildings can vary, and in buildings that have high levels of safety in place, different complications may emerge. Therefore, for a building to be deemed safe in the event of a fire, it is essential to provide a user-focused, safe evacuation means.

OBJECTIVE AND META-ANALYSIS

Human behavior plays a crucial role in ensuring effective evacuation. Therefore, fire safety in buildings cannot be fully ensured solely through meeting fire-safe design regulations and legal requirements; instead, a comprehensive approach that offers solutions tailored to building- and user-specific attributes is deemed vital. In fire-safe building design, by developing solutions that address risks associated with different users directly in interaction with the building's function, risks can be eliminated, casualties can be prevented, or loss of life can be minimized.

The study involves quantitative research aimed at identifying user behavior patterns and potential risks in buildings with different functions. The objective is to determine the degree and impact of variable user-related factors on fire safety in buildings, ensuring that evacuation is carried out in a timely and safe manner. The study also aims to conduct a comprehensive analysis by combining data derived from various research studies and to identify the critical factors necessary for user safety. The criteria obtained through the meta-analysis method are tested by comparing them with real fire incidents, and their effectiveness is evaluated accordingly. The research can contribute to the development of fire safety measures by considering users' needs and expectations. By basing these factors on real fire incidents, the aim is to reduce the damage caused by fires and enhance the effectiveness of fire safety measures.

Identifying the risks associated with building occupants who need to be evacuated during a fire is crucial for understanding user characteristics, response times, and behavior patterns, as well as for developing effective evacuation strategies. According to the Society of Fire Protection Engineers (SFPE, 2016), information on the number of occupants, activities conducted within the building, and the interactions among users should be compiled, and user-related risks should be identified. To do this, first, the class of the building must be established. Building classes define the environment of the users, the resources used in the building, hazards, and social hierarchy, and they have an effect on the types of activities carried out in a specific area. Additionally, building classes are related to the users' familiarity with the building and the conditions under which they use it (SFPE, 2016). This information impacts the design of fire escape and protection systems and provides insights into the time it takes for users to reach a safe location from the moment they begin to move to escape the fire. Moreover, information on how users identify danger cues, respond to them, and when they decide to evacuate is also crucial data for understanding their evacuation decision processes (Meacham, 2000).

According to the National Fire Incident Reporting System (NFIRS), buildings are categorized under the following ten classes (FEMA, 2015):

- Assembly Buildings (1st Class)
- Educational Buildings (2nd Class)
- Health Care, Detention, and Correction Buildings (3rd Class)
- Residential Buildings, Accommodational Facilities (4th Class)
- Business/Commercial Buildings (5th Class)
- Industrial, Utility, Defense, Agricultural, Mining Buildings (6th Class)
- Manufacturing and Processing Buildings (7th Class)
- Storage Buildings (8th Class)
- Open Spaces (9th Class)
- Unclassified or Special Property Buildings (10th Class)

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In this study, user-related risks were ascertained through meta-analysis following a systematic literature review. Meta-analysis is a scientific technique employed to achieve the most optimal outcome by first identifying results obtained from a series of scientific studies, then eliminating infrequently observed outcomes and synthesizing those frequently observed. To effectively answer a research question, it is imperative that meta-analysis be conducted as an integral part of the systematic review (Nordmann et al, 2012). The most significant characteristic of a systematic review is that the studies selected for inclusion are searched within specific databases and are recognized as scientifically valid.

In the research conducted using meta-analysis, Scopus and ScienceDirect databases were used for literature searches. The search was based on the titles and abstracts of the articles and some specific keywords selected. The search was limited to the years 2000–2023.

Keywords used for the literature review:

- Fire Evacuation
- Human Behavior in Fire
- Human Behavior
- Emergency Evacuation
- Risk Assessment

As a result of the search, the publications to be evaluated in the study were required to meet the following criteria:

- To be published in a peer-reviewed journal indexed in the SCI
- To be written in English
- To contain inferences made about user behavior during a fire

As a result of the search conducted according to the keywords, a total of 987 sources were identified, and after eliminating duplicate publications, 854 articles were reviewed. Upon scanning the abstracts of 153 articles that advanced to the next stage as determined by the title search, the full text of 59 articles deemed suitable for the study was read entirely. This review concluded that 28 articles met the criteria for inclusion in the study. Subsequently, the findings from these studies were consolidated, resulting in the identification of 11 user-related risk categories, which were grouped for building fire safety through meta-analysis (Figure 1).

User-related risks assessed through meta-analysis were found to be addressed in varying numbers across the 28 publications reviewed. The risks with the highest mention were physical condition and crowd effect, in sixteen publications. These are followed by decision-making mentioned in fourteen publications, age in thirteen publications, and kinship/affinity in twelve publications. The lowest number of mentions was for dependency relationship, which appeared in only four publications (Figure 2).

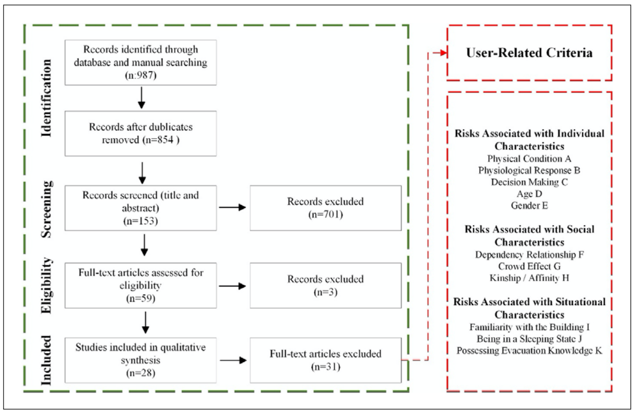


Figure 1. PRISMA Flowchart for Determining Fire Safety Criteria.

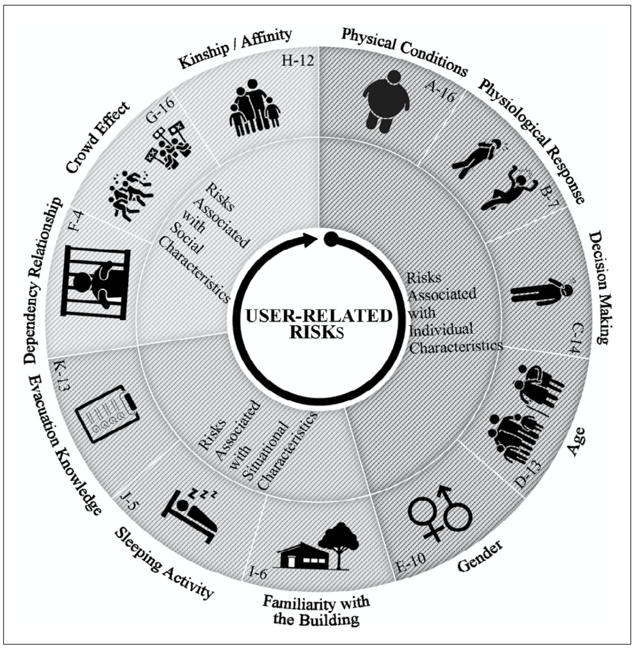


Figure 2. Grouping of User-Related Risks Identified Through Meta-Analysis and Their Mention Counts in Publications.

USER-RELATED RISKS IN FIRE-SAFE BUILDING DESIGN

In this study, user-related risks to take into consideration in designing fire-safe buildings are examined in three groups: risks associated with individual, social, and situational characteristics.

Risks Associated with Individual Characteristics

Risks associated with individual characteristics include physical condition, physiological response, decision-making, age, and gender.

Physical Condition: The time it takes for users to decide to initiate evacuation and subsequently perform evacuation actions is a critical factor in determining the total evacuation time required. The physical conditions of the users directly affect the evacuation duration (Tubbs & Meacham, 2007). In some buildings, a portion of the occupants may be physically disabled or have physical restrictions due to medical conditions such as injuries or illnesses. Pre-existing medical conditions of the users have an immediate effect on evacuation during a fire. Moreover, some users may require full assistance from others to be evacuated or may not be movable at all (Shields et al, 1999). In such cases, a significant preparation time may be required before assisting users with mobility limitations.

The movement of users with disabilities is significantly restricted by building elements such as doors, ramps, and stairs. While the evacuation movements of users with hearing impairments may not differ from those without disabilities, they often require specialized fire warning devices. Although users with visual impairments are able to perceive fire alarms and audible warnings, they would likely need assistance from others to locate an appropriate evacuation route. Additionally, when users with disabilities enter the stairwell, they will move slower than the evacuating group, so the overall evacuation speed of the building decreases, and the evacuation time is prolonged (SFPE, 2019).

Users with special mobility needs and those who can only be evacuated with assistance face difficulties in reaching a safe place during emergencies (Bukowski, 2007). The Inter-jurisdictional Regulatory Collaboration Committee (IRCC) emphasizes that as people's life expectancy increases, the proportion of elderly individuals in the global population also rises, making it essential to consider the reduced mobility associated with aging when developing fire safety plans. Such physical conditions directly impact the evacuation performance of buildings (IRCC, 2003).

Physiological Response: User responses during emergencies can vary significantly. Therefore, these responses should be considered in fire safety planning for buildings. Having the ability to identify fire cues, recognize that the situation is an emergency, decide on what to do, and execute the necessary actions is critical for ensuring user safety. In building design, identifying the user and assessing their behavior during emergencies in advance impacts various aspects of exit system design, from selecting appropriate alarm systems to determining the time required for evacuation (Tubbs & Meacham, 2007).

Evacuation plans typically indicate a single exit route, and when this route is obstructed or clogged by overcrowding, no alternative route is suggested. However, in emergencies, people often do not follow safety signs; they may react unpredictably due to panic and concerns about not being able to evacuate quickly (Rendón Rozo et al, 2019). In interviews conducted following fires, users who experienced the event have frequently reported succumbing to panic during the incident. Moreover, the limited knowledge and experience that users possess regarding the progression of fires and fire dynamics often lead them to respond inappropriately during fire emergencies. It is frequently observed that at the initial onset of a fire, when the smell of smoke is detected or the fire alarm sounds, users often fail to react or choose to ignore the fire. This behavior is particularly thought to stem from users in public buildings not wanting to respond to what they perceive as a false alarm or a fire that will be controlled. Such disregard or acceptance of a hazardous situation often results in delays in initiating evacuation or taking protective measures. Additionally, the evacuation process can be further prolonged as users engage in actions like locating family members and pets, dressing according to the weather, and gathering personal belongings (SFPE, 2019).

Decision-Making: After receiving one or more fire cues, noticing the fire, and interpreting it correctly, users must then decide what to do next (Donald & Canter, 1992). However, studies have shown that when the risk perceived by the user in any emergency situation is low, users tend to exhibit passive behavior and ignore the situation, thinking it does not pose a threat. This implies that perceived risk is strongly associated with the response time and the initiation of the evacuation action. After an evacuation decision has been made, the escape time depends on the occupants' selection of exit routes and how fast they evacuate (Cvetković et al, 2022).

The time it takes for users to decide to begin evacuation and then carry out evacuation actions are critical factors in determining the total evacuation time required. In some cases, this may be directly related to cognitive abilities, building usage, or the activities that take place within the building. For instance, in treatment centers for individuals with intellectual disabilities, elderly care homes, or special care facilities, users may have difficulty recognizing the need for evacuation, moving themselves to a safe location, or both. It is also important to note that in environments where alcohol is consumed, users' response times to emergencies may be prolonged, and their ability to react may be impaired (Boyce et al., 2017).

In entertainment venues with flashing lights or features similar to fire signals, the time it takes for users to perceive a fire may be longer. Additionally, users' fear of losing money or valuables can prolong the escape time. Another factor is the potential for users to have certain limitations that delay their decision-making and response times. These limitations can be perceptual, physical, or cognitive, or they may result from the use of prescription drugs. Moreover, if the users are elderly persons or children, they may also have limited cognitive capacity to carry out protective actions (SFPE, 2019).

Age: During emergency evacuations, users from different age groups are anticipated to demonstrate dissimilar evacuation performances. The performance differences among various age groups are categorized into three groups: sensory skills, decision-making, and action-taking. There are significant differences in evacuation times among these groups. Moreover, the irregular nature of this factor makes it difficult to predict evacuation time (SFPE, 2019). Age is also expected to affect users' ability to withstand the effects of a fire. Elderly individuals, in particular, are the most at-risk group due to factors such as limited mobility, quick fatigue, cognitive impairment, and suffering from vision or hearing impairments. Additionally, elderly individuals often resist evacuation (Jenkins et al, 2007). Similar to individuals over the age of 65 (Chien & Wu, 2008), children under the age of 5 are also considered to be among the high-risk group (Cvetković et al, 2022).

Gender: In general, women are more likely than men to warn others and evacuate the building in response to fire cues (Nilsson et al, 2008). In residential buildings, men are more likely to attempt to fight the fire, while women are more likely to gather family members and call the fire department. Additionally, studies have shown that men have a higher fatal injury rate than women across all five of the most common fire risk statistics (Mulvaney et al, 2009). In a study on the behavior of occupants during fires in healthcare facilities, it was observed that male staff tended to fight the fire, while female staff, consistent with their training and assigned responsibilities, were more inclined to take protective measures and rescue patients (SFPE, 2019).

Risks Associated with Social Characteristics

Risks associated with social characteristics include dependency relationships, crowd effects, and kinship/affinity conditions.

Dependency Relationship: Due to dependency relationships closely related to individuals' physical and cognitive conditions, the time required for user evacuation emerges as the most critical factor for life safety. The evacuation of vulnerable persons, particularly those admitted to healthcare facilities, poses significant challenges due to potential physical and cognitive limitations of these individuals (Ahn et al, 2022). Studies demonstrate that nursing homes and similar facilities need to develop specialized evacuation plans that account for the diverse mobility needs of their residents, including those who are bedridden or rely on wheelchairs and other assistive equipment to move around (Kim et al, 2010).

In daycare centers, kindergartens, and other buildings housing a large number of infants and young children, users are dependent on adults for their safety during a fire. In buildings where the staff is required to guide visitors or users to appropriate exits, such as prisons or buildings with restricted access, users rely on others for evacuation or exit doors to be opened. In such situations, as much as the building design and staff training, developing user-appropriate evacuation strategies is considered crucial (Tubbs & Meacham, 2007).

Crowd Effect: When designing exits for crowded spaces, it is essential to consider crowd psychology and behavior. Crowds are influenced by various factors, such as their formation reasons, user characteristics, and various internal and external stimuli. Understanding these factors can be helpful in assessing and managing crowd behaviors. Studies show that users following an evacuation route tend to change their initial route selection decisions under the influence of swarming crowds (Zhang et al, 2023).

Crowds can be classified into different types such as calm crowds, mobile crowds, and emotional crowds (Durupinar et al, 2016). Therefore, many crowds exhibit different characteristics from the moment they start gathering to the moment they disperse when a specific event takes place. Crowd dynamics are impacted by various factors such as psychological parameters, social forces, and environmental conditions (Park et al, 2021). For instance, a conference hall and an open-air festival venue may hold the same capacity; however, while individuals gathered in a conference hall tend to follow instructions calmly and in an orderly manner, it is possible for the crowd at an open-air festival to become unruly due to heightened emotional intensity. Similarly, a library and a sports event venue may have the same capacity, but it should not be forgotten that although people in a library generally act calmly and orderly during an emergency, the crowd attending a sporting event may become uncontrollable due to factors triggering their emotional state.

Kinship/Affinity: During a fire, the presence of individuals within the burning building who are close to or relatives of the users significantly influences the users' emergency behavior and decision-making abilities. Responses to alarms or fire cues may vary depending on whether users are alone or in the company of others. The presence of other individuals plays an inhibitory role in identifying and initiating user mobility (Proulx, 2001). On the other hand, the presence of others can increase the likelihood of users being aware of an emergency situation and facilitate making group decisions regarding which actions to take (SFPE, 2019).

Research on human behavior during evacuation reveals that multiple factors influence people's evacuation decisions in emergencies. The presence of children in the building increases the likelihood of evacuation (Fischer et al, 1995), while being with kinspersons can lead to delays in evacuation and increases in dependency behaviors (Shentu et al, 2018). For instance, the scenario of evacuating a large building with strangers will differ from that of evacuating with parents and children. In such situations, social relationships or affinity can either prolong or shorten the time it takes for users to respond to emergency alerts (Bode et al, 2015).

Risks Associated with Situational Characteristics

Risks associated with situational characteristics include familiarity with the building, sleeping activity, and evacuation knowledge.

Familiarity with the Building: Users' response during a fire can be affected by their familiarity with the building and the building's security systems. Those who use the building frequently may have exact knowledge about where the nearest and alternative exits are and which warning systems the building has. Especially when users participate in emergency training programs and evacuation drills regularly, they are anticipated to carry out more efficient evacuations. However, those who use the building less frequently often rely more on signage and staff. These users may be less familiar with and less sensitive to warning systems. After deciding to evacuate, these users may attempt to exit the building through the route they entered unless directed otherwise by signs or security systems. Even if there are exit signs, users may not notice them and may not proceed toward these exits (Nilsson et al, 2008).

In an emergency, users are unlikely to be willing to try a route they have never used before to evacuate the building. However, if the exit route they are familiar with is filled with smoke or congested with crowds, and therefore unusable, they may prefer to follow exit signs to find an alternative exit. In such situations, exit signs should be highly visible and attention-grabbing to be distinguishable from the surrounding information and easily noticeable by building occupants (SFPE, 2019).

Sleeping Activity: When users are asleep, their response time to fire alarms is anticipated to be significantly delayed (Bruck, 2001). In the event of a fire breaking out at night, as users are asleep, they will require a longer time for evacuation or may not be evacuated if they are not alerted by others (SFPE, 2019). Therefore, since sleeping activity affects the response to fire cues, users may be at greater risk compared to when they are awake (Ball & Bruck, 2004).

In the event of a fire, if there are additional risks in the building, sleeping activity is assumed to be a significant risk factor for loss of life. Studies on smoke alarms and sleeping activity have shown that factors such as the presence of high levels of background noise, users being in deep sleep, users suffering from sleep deprivation, users being children, users being under the influence of sleep medications or intoxicated, and users being hearing impaired can be associated with additional risks when users are in a sleeping state (Bruck & Ball, 2005).

Evacuation Knowledge: When a fire cannot be extinguished immediately and an evacuation decision is made, a pre-planned and organized evacuation process must be initiated promptly. Delaying the decision to evacuate may lead to loss of life. Therefore, it is crucial that users, staff, or emergency response teams have received training on the responsibilities to be assumed and evacuation procedures, which should be put to use in case of a fire (Tubbs & Meacham, 2007). In buildings where the user load is dense or occupied by users in high-risk groups, fire evacuation bears significant risks, and having emergency plans in place and conducting prior drills becomes of vital importance (Wang et al., 2021). Users who are given regular training on emergencies and who participate in evacuation drills are anticipated to carry out evacuation processes more efficiently (SFPE, 2019).

Emergency evacuation drills are conducted to test the effectiveness of emergency warnings. Generally, emergency evacuation and relocation drills should be conducted with adequate frequency to ensure that building occupants become sufficiently familiar with the procedures. The frequency and methods of emergency evacuation drills may vary depending on the type of building use (NFPA, 2019). The International Fire Code (IFC) indicates that conducting fire escape and evacuation drills is an essential practice to ensure the evacuation of users to a designated assembly point and to provide users with experience in using appropriate exits (IFC, 2012).

EVALUATION OF USER-RELATED RISKS THROUGH SAMPLED FIRE INCIDENTS

Numerous fires that have occurred in the past have resulted in loss of life and property, contingent upon environmental conditions, the nature of the fire, the manner in which the fire impacted the building and its occupants, and the user profile. The eighteen fires exemplified in this study demonstrate that excessive fatalities stem from fire safety measures not being harmonized with user attributes, highlighting the imperativeness of developing innovative strategies for implementing necessary precautionary measures.

In the study, fires that have occurred particularly in a period from the beginning of the 21st century to the present (2004–2024) were examined, and from among these, eighteen fires that took place in buildings with different functions and resulted in high fatalities were selected as samples. The samples in the set were selected with the intent to determine the variability of user-related risks in buildings with different functions and to identify these risks. Of the buildings selected as samples where fires were encountered, three are in the USA and Russia, two in Iraq, and the others are located in India, Scotland, Thailand, Russia, Honduras, Bangladesh, South Korea, the United Kingdom, China, Egypt, Vietnam, and Iran (Table 1).

Table 1. User-Related Risks Perceived in Sampled Fire Incidents

Name of the Fire	**Rosepark Care Home**	**Kumba-konam School**	**Santika Night-club**	**ABC Daycare Center**	**Lame Horse Nightclub**	**Comay-agua Prison**	**Tazreen Fashion Factory**	**Kiss Night-club**	**Psychi-atric Hospital**	**Grenfell Tower Residential Building**	**Sejong Hospital**	**Zimnyaya Vishnya Mall**	**Ibn al-Khatib Hospital**	**Zhenxing Martial Arts School**	**Church in Giza**	**Hanoi Residential Building**	**Qaraqosh Wedding Hall**	**Drug Rehab. Center Iran**	**Total**
Date of the Fire	January 31, 2004	July 16, 2004	January 1, 2009	June 5, 2009	December 5, 2009	Febru-ary 14, 2012	November 24, 2012	January 27, 2013	April 26, 2013	June 14, 2017	January 26, 2018	March 25, 2018	April 24, 2021	June 25, 2021	August 14, 2022	September 12, 2023	Septem-ber 26, 2023	Novem-ber 3, 2023	
City/Country	Glasgow / Scotland	Kumba-konam / India	Bang-kok / Thai-land	Her-mosillo / Mexico	Perm / Russian Federation	Comay-agua / Hondu-ras	Ashu-lia-Dhaka / Bangladesh	Santa Maria / Brazil	Moscow / Russian F.	London / UK	Miryang / South Korea	Kem-erovo / Russian F.	Baghdad / Iraq	Henan / Republic of China	Cairo / Egypt	Hanoi / Vietnam	Nineveh / Iraq	Langarud / Iran	
Number of Casualties	14	93	66	49	156	361	112	242	38	79	47	60	82	18	41	56	114	32	1660
Number of Injuries	4	21	222	131	140	21	200	300	3	70	145	68	110	16	45	37	150	16	1699
Physical Condition																			
Hearing im-paired																			0
Visually im-paired																			0
Walking im-paired Bedrid-den patients	■									■	■		■						4
Physiological Response																			
Those who succumb to panic		■	■	■	■		■	■		■		■		■	■	■	■	■	13
Those who are unresponsive, indifferent	■					■			■		■		■						5
Decision-Making																			
Those who are tardy in deci-sion making			■		■	■		■						■	■		■		7
Those who can't decide on their own	■	■		■					■		■		■					■	7

Table 1. User-Related Risks Perceived in Sampled Fire Incidents. (Cont.)

Age																			
18-65 years of age			■		■	■	■	■	■									■	7
All ages										■		■	■		■	■	■		6
6-17 years of age		■												■	■				3
0-5 years & 65 years and over	■			■							■								3
Gender																			
Female users	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	0
Mixed-gender users																			18
Male users																			0
Dependency Relationship																			
Not having dependency relationship	■	■		■		■			■	■	■	■	■	■	■			■	12
Crowd Effect																			
Calm Crowd		■				■	■					■		■					5
Mobile Crowd			■		■			■									■		4
Emotional Crowd															■			■	2

Table 1. User-Related Risks Perceived in Sampled Fire Incidents. (Cont.)

Kinship / Affinity																			
A bunch of friends being present	■	■	■		■		■	■				■		■	■		■		10
Family members being present										■		■			■	■	■		5
Familiarity with the Building																			
Being unfamiliar with the building			■		■	■		■	■		■	■	■		■		■		10
Sleeping Activity																			
Sleeping activity taking place	■			■	■	■			■	■	■		■	■		■		■	11

Fires that have occurred not only in the countries where the sampled buildings are located but also in other nations demonstrate that similar outcomes can manifest anywhere. They expose past mistakes, uncover the causes of these fires, and underscore the importance of the analyses conducted. These findings may play a significant role in reducing user-related risks in the future and decreasing the likelihood of similar fires recurring. User-related issues are quite prevalent during fire evacuations. Among these issues, factors such as the effect of crowds on individuals, the need for assistance during evacuation, efforts to evacuate with family members, sleeping activity, age, and physical or cognitive conditions of the users hold significant importance. Particularly in emergencies where users do not fully know how to act or require guidance—such as in daycare centers, kindergartens, prisons, or shopping malls—experiences gained from past fires are considered vital for identifying risks. Therefore, the selected samples are examined through a detailed evaluation in terms of user-related risks (Table 2).

The fires examined as examples in the study facilitate the identification of user-related risks. It is observed that the risks leading to these fires are associated not only with the characteristics of the fire and the building but also with the users themselves. In the fires of buildings with different functions analyzed within the scope of the study, a total of 1,660 people lost their lives, and 1,699 were injured. The highest number of fatalities, amounting to 361 individuals, occurred in the Honduras Prison fire on February 14, 2012. The fire with the highest number of injuries, involving 200 people, was the Kiss Nightclub fire in Bangkok, Thailand, on January 27, 2013.

Users who were exposed to the fire at Grenfell Tower with mobility impairments, along with bedridden patients hospitalized at Ibn al-Khatib Hospital and Rosepark Care Home, are considered high-risk users in terms of their physical conditions. Regarding physiological responses, users in the fourteen buildings where the sample fires occurred experienced panic; users in two hospital buildings did not respond to the fires, whereas users in the psychiatric hospital and prison disregarded the fire altogether. In five of the buildings, users made swift decisions to evacuate; in six buildings, the initiation of evacuation was delayed; and in seven buildings, no decision to evacuate was made at all.

In terms of age, the most at-risk buildings are Sejong Hospital, ABC Daycare Center, Rosepark Care Home, Zhecheng, and Kumbakonam School. In terms of gender, users in all buildings were both female and male; however, of the fourteen users who lost their lives in the Rosepark Care Home fire, thirteen were women.

In all eighteen fire cases examined, it has been observed that all the users lacked evacuation knowledge regarding how to evacuate the building in the event of a fire. The panic experienced, the assistance required, the unfamiliarity with the building, and the disabilities among the users have been determined as secondary risk factors in fires where the fatality rates were high (Figure 3).

There is a dependency relationship in twelve of the buildings where children, users over the age of 65, bedridden patients, users with mobility impairments, and prisoners were present. In eleven of the eighteen buildings, crowd effect was observed in varying degrees. In terms of kinship/affinity, in six of the buildings, users were alone by themselves. In seven of the buildings, users were familiar with the buildings as they were using them regularly. Although the users in Comayagua Prison were permanent users of the building, they lacked familiarity with it. Sleep activity was a factor in eleven of the buildings. In all eighteen fire cases examined, it has been observed all the users lacked evacuation knowledge regarding how to evacuate the building in the event of a fire.

ANALYSIS OF USER-RELATED RISKS IN FIRE-SAFE BUILDING DESIGN

In the study, user-related risks, categorized into three groups based on their association with individual, social, and situational characteristics, were analyzed, and each risk group was rated according to their risk levels within (Figure 4). Correspondingly, four risk categories were identified in this rating: Risk-free, Low-risk, Moderate-risk, and High-risk.

The risks identified in the literature studies were graded by taking into account the occurrence of eighteen fire cases examined and their relationship with loss of life. For example, in the Rosepark nursing home fire, there were 43 users in the building in total. The presence of users with walking disabilities and users over 65 years of age in the building were determined as the risk types that caused approximately 35% of the users to lose their lives. Within the scope of the study, these two risk types are rated as high risk. In Ibn al Khatib hospital in Iraq, which is used for the treatment of Covid 19, the fact that the users do not have a consciousness to react to fire and are being treated as inpatients is seen as high risk. In the substance addiction rehabilitation centre in Iran, the fact that the users were being treated with medication created the risk of not reacting, not caring and not making decisions in case of fire and increased the number of casualties. In the Comayagua prison fire, the fact that the inmates needed the help of others to escape and their individual escape was not possible showed that the risk of dependent relationship in the building was at a high level and this situation was rated as high risk.Sleeping is considered as a risky factor in all buildings. However, one of the most tragic examples of this situation, the Grenfell Tower fire, resulted in the loss of 79 lives. Panic was observed in almost all of the fires with high loss of life. In addition, crowded use and the presence of family members in the building also increased the loss of life. In this context, the presence of visually impaired users, panicking individuals, those who experience delay in decision-making process, the presence of users between the ages of 6-17, the majority of the deceased being male and the absence of any evacuation plan in the building were evaluated in the medium risk group.

Analysis of Risks Associated with Individual Characteristics

In terms of risks associated with physical condition: users without disabilities are classified as risk-free; hearing-impaired users as low-risk; visually impaired users as moderate-risk; and those with mobility impairments, as well as bedridden patients, as high-risk groups.

In terms of risks associated with physiological responses, which are critical for initiating the evacuation process: users who remain calm during a fire are classified as risk-free; those who succumb to panic as moderate-risk; and those who are unresponsive and indifferent to the fire as high-risk groups.

In terms of risks associated with decision-making: users who swiftly decide to commence the evacuation process are classified as risk-free; those who delay in decision-making—such as individuals in game rooms, children, and the elderly—as moderate-risk; whereas those incapable of making decisions, those with mental disabilities, those under the influence of alcohol, and those using red-listed medication are classified as high-risk groups.

In terms of risks associated with age: users between the ages of 18 and 65 are classified as risk-free; users aged 6 to 17 as moderate-risk; whereas those aged 0 to 5 and 65 or older are classified as high-risk groups.

In terms of risks associated with gender: female users are classified as risk-free; mixed-gender users as low-risk; whereas male users are classified as moderate-risk groups.

Analysis of Risks Associated with Social Characteristics

In terms of risks associated with dependency relationships: the absence of a dependency relationship is classified as risk-free, whereas the presence of a dependency relationship is classified as high-risk.

In terms of risks associated with crowd effect, which display different characteristics from formation to dispersion: The absence of crowds in the building is classified as risk-free; the presence of a calm crowd as low-risk; a mobile crowd as moderate-risk; and an emotional crowd as high-risk.

In terms of risks associated with kinship/affinity: The absence of any persons in a close relationship with the

Table 2. Explanation about the Sampled Fire Incidents

Name of the fire	Explanation about the fire	Image of the fire
Rosepark Care Home	In the Rosepark Care Home fire, one of the selected case studies, the inability to provide assistance to users over the age of 80 during the fire prevented a safe evacuation, resulting in fatalities. Furthermore, the inadequate emergency training of the building staff led to room doors being left open during the incident, allowing smoke to spread, which increased the number of casualties (Purser, 2017; Crowder, 2015).	 (McArdle, 2011)
Kumbakonam School	In the fire broke in Kumbakonam School of India, ninety-three children perished because they were unable to receive assistance during the evacuation. The narrow stairways and the presence of only a single exit point impeded emergency evacuation, while inadequate evacuation procedures rendered a safe escape impossible (Walia & Satapathy, 2007).	 (Chauhan, 2019)
Santika Nightclub	In the fire broke in Santika Nightclub of Bangkok Thailand, the consumption of alcohol within the venue, overcrowding, and inadequate emergency evacuation planning resulted in fatalities and injuries. Patrons whom were under the influence of alcohol panicked, thereby hindering safe evacuation, and the ensuing crowd congestion led to the blockage of escape routes (Bromann, 2009).	 (Paddock & Suhartono, 2022)
ABC Daycare Center	In the ABC Daycare Center fire in Mexico, children under the age of 5 were unable to receive support for evacuation, leading to numerous fatalities. Locked doors and the only exit being through the administrative office hindered the safe evacuation (Greenhalgh et al., 2012).	 (BBC News, 2015)
Lame Horse Nightclub	In the Lame Horse Nightclub fire in Russia, toxic smoke emitted by fireworks caused people to panic and head towards a single exit. The dark and crowded environment further increased the number of casualties (Foley, 2019).	 (Telichenko & Roitman, 2020)
Comayagua Prison	In the fire broke in Comayagua prison of Honduras, resulting in the loss of 361 lives, 46 of those being women. The lack of fire alarms, sprinkler systems, and smoke detectors in both buildings where the inmates were held allowed the fire to spread rapidly from one building to another. Since the keys to release the prisoners could not be found, many inmates lost their lives by burning or suffocating in their cells. The overcrowded conditions of the facilities contributed to the increase in casualties (Moncada, 2012).	 (Reddy & Aleman, 2012)
Tazreen Fashion Factory	In the Tazreen Fashion Factory fire in Bangladesh, the presence of highly flammable materials, overcrowding, and narrow exit routes prevented the safe evacuation of the 1,400 workers in the building, leading to increased fatalities and injuries (Ullah, 2022). In the Kiss Nightclub fire in Brazil, alcohol consumption, the presence of fireworks, locked exit doors, and inadequate emergency measures increased fatalities and hindered rescue efforts (Gragnani et al, 2017).	 (Manik &Yardley, 2012)
Kiss Nightclub	In the Kiss Nightclub fire in Brazil, alcohol consumption, the presence of fireworks, locked exit doors, and inadequate emergency measures increased fatalities and hindered rescue efforts (Gragnani et al, 2017).	 (Barbassa, 2013)

Table 2. Explanation about the Sampled Fire Incidents (Cont.)

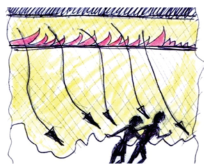
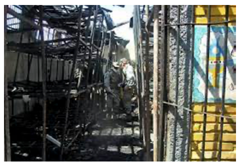
Name of the fire	Explanation about the fire	Image of the fire
Psychiatric Hospital	In the fire at the psychiatric hospital in Ramensky village, Moscow, most of the residents perished, with only three people surviving. The rapid spread of the fire caused a stampede, leading to the deaths of some patients who became trapped at the barred windows.	 (VoaNews, 2013)
Grenfell Tower Residential Building	In the fire broke in the Grenfell Tower residential building in London claimed the lives of 79 people. The fire, which originated from a refrigerator found in the kitchen of apartment 16 on the 4th floor, spread throughout the entire building. Due to the lack of a fire escape staircase in the 24-story building, which housed 129 separate units and approximately 350 residents, occupants were trapped inside the building during the fire. As the fire rapidly spread throughout the building, trapped occupants awaited to be rescues, and four people lost their lives by jumping from the building (Parkinson, 2017). 15 out of 37 disabled users and 17 out of 67 children occupants lost their lives in the fire (Potton et al, 2017).	 (Gillett, 2017)
Sejong Hospital	In the Sejong Hospital fire in South Korea, a fire that started in the electrical wiring in the ceiling of the pantry spread rapidly to the adjacent Sejong Nursing Hospital. This resulted in numerous fatalities, particularly among patients aged 80 and over suffering from severe illnesses such as dementia. The lack of evacuation procedures for fire emergencies in the hospital further complicated rescue efforts (Choi et al, 2022).	 (BBC News, 2018)
Zimnyaya Vishnya Shopping Mall	In the Zimnyaya Vishnya Shopping Mall fire, numerous fatalities occurred due to security breaches, the failure to implement fire safety measures in accordance with regulations, and the malfunctioning of fire circuit breakers in the lighting system. Additionally, in one of the cinemas where the roof collapsed, the absence of an audible alarm and the need to break down a door to escape further increased the number of casualties (Ryabov et al, 2022).	 (AKIpress, 2018)
Ibn al-Khatib Hospital	In the fire at Iraq's Ibn al-Khatib Hospital, where COVID-19 patients were being treated, an explosion of oxygen tanks sparked a blaze. Twenty-eight people attempted to flee by removing their ventilators, but physical and cognitive impairments prevented them from evacuating the building, leading to an increase in casualties (Tawfeeq, 2021).	 (NYT, 2021)
Zhenxing Martial Arts School	In the fire at the Zhenxing Martial Arts School in China, eighteen out of thirty-four students, mostly aged between seven and sixteen, lost their lives. The lack of fire safety inspections at the school heightened the risks (BBC News, 2021).	 (Usaini, 2021)
Church in Giza	The Giza Church fire in Egypt broke out from a faulty air conditioning unit during a Sunday service attended by 5,000 people. The fire spread to the nursery inside the church, resulting in the deaths of forty-one people, including eighteen children, and injuries to forty-five others. In the fire, children could not escape alone in case of panic and there was a stampede due to the crowd, which increased the number of casualties and injuries (Egypt Today, 2022).	 (Egypt Today, 2022)

Table 2. Explanation about the Sampled Fire Incidents (Cont.)

Name of the fire	Explanation about the fire	Image of the fire
Hanoi Residential Building	A fire broke in a nine-story residential building in Hanoi, Vietnam, caused widespread panic among the 150 residents, forcing some to jump from the building. The fire started in the basement area where motorcycles were stored and took twelve hours to bring under control (Mid-day, 2023a).	 (Minh, 2023)
Qaraqosh Wedding Hall	In the fire at the wedding hall in Qaraqosh Iraq, the presence of a thousand people over the venue's capacity and the lack of emergency exits escalated panic and confusion, posing a significant risk. Additionally, the use of highly flammable sandwich panel cladding on the exterior contributed to the rapid spread and intensification of the fire (Silliman, 2023)	 (Mando et al, 2023)
Drug Rehabilitation Center Iran	The fire at the drug rehabilitation center in Iran started when a heater ignited the curtains. With over forty patients asleep and the doors locked, caused the number of fatalities to increase. The patients' inability to make evacuation decisions heightened the impact of the fire (Mid-day, 2023b)	 (Apa News, 2023)

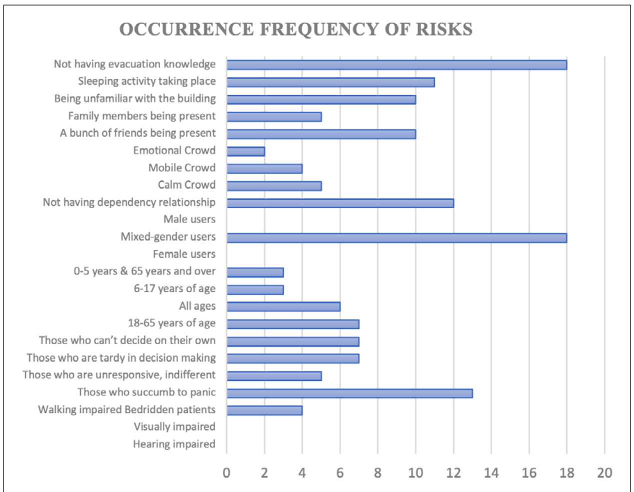


Figure 3. The Occurrence Frequency of Risks Contributing to the Fires.

		Risk-free	Low-risk	Moderate-risk	High-risk
Risks Associated with Individual Characteristics	Physical Condition	Persons with no disabilities	Hearing impaired persons	Visually impaired persons	Walking impaired persons / hospitalized patients
	Physiological Response	Those who remain calm		Those who get into panic	Those who do not respond or are indifferent
	Decision Making	Those who can decide fast		Those who delay to make a decision	Those who cannot decide on their own
	Age	Those aged between 18-65 y/o	All ages	Those aged between 6-17 y/o	Those aged between 0-5 y/o or above 65 y/o
	Gender	Females	Mixed gender usage	Males	
Risks Associated with Social Characteristics	Dependency Relationship	No dependency relationship			Having dependency relationship
	Crowd Effect	No crowds	Calm crowds	Mobile crowds	Emotional crowds
	Kinship / Affinity	No kinship / affinity among users	Having groups of friends	Having family members	
Risks Associated with Situational Characteristics	Familiarity with the Building	Being familiar with the building		Being unfamiliar with the building	
	Being in a Sleeping State	Buildings where no sleeping activity takes place			Buildings where sleeping activity takes place
	Possessing Evacuation Knowledge	Those who have knowledge about how to evacuate		Those who don't have knowledge about how to evacuate	

Figure 4. Classification of User-Related Risk Levels.

users in the building is classified as risk-free; the presence of a group of friends as low-risk; whereas the presence of immediate family members is classified as moderate-risk.

Analysis of Risks Associated with Situational Characteristics

In terms of risks associated with familiarity with the building: users who are familiar with the building are classified as risk-free, while those unfamiliar with the building are classified as moderate-risk.

In terms of risks associated with sleep activity, which is a significant cause of fatalities in fires: buildings where no sleep activity takes place are classified as risk-free, whereas buildings where sleep activity is carried out (along with additional risks associated with sleep activity) are classified as high-risk.

In terms of risks associated with evacuation knowledge: users who are knowledgeable about how to evacuate the building are classified as risk-free, while those lacking evacuation knowledge are classified as moderate-risk.

CONCLUSION

Fire safety analysis is a systematic process that aims to preemptively identify risks that may arise during a fire and to develop effective measures against these risks. When considered historically, the aftermaths of past fires underscore the necessity and significance of such analyses. Numerous fires that have occurred in the past have served as a guide regarding the precautions to be taken against fires in buildings, leading to many changes and new regulations in fire-safe building design.

Particularly, the advancements derived from the insights and lessons of past fires concerning the evacuation of buildings exposed to fire are of paramount importance. However, it is still observed today that the measures taken against fire are not at an adequate level. The loss of life resulting from fires in buildings constructed without considering the functions of the buildings, the building materials used, spatial configurations, the environment and zoning conditions where the building is located, and the user profile and number is a serious indicator that the necessary measures against fire have not been taken or, even if taken, have been insufficient.

Moreover, although rules aimed at preventing incidents resulting from fires have been established in codes, standards, and regulations, the absence of design rules compatible with users and the failure to design escape routes in accordance with these rules constitute significant deficiencies.

When conducting building fire safety analyses, in addition to the characteristics of the building and the fire itself, the attributes of the user group or groups should also be identified, and necessary fire safety measures should be considered with a holistic approach.

One of the most complex components in the evacuation process during fires is the user. The data obtained from the study reveal that user risks associated with their physical, psychological, and social characteristics have a direct impact on the effectiveness of the evacuation process.

Therefore, to ensure that evacuations from buildings exposed to fire are conducted effectively and safely, and to prevent loss of life in fires, it is necessary to identify not only the risks associated with the building and the fire but also those associated with the user. In the study, user-related risks that may be encountered during a fire were examined under three main categories based on individual, social, and situational characteristics, and these were subsequently classified in detail. This risk classification is of critical importance for the effectiveness and safety of the evacuation process.

To ensure the rapid and safe evacuation of users during a fire, it is of dire importance that fire safety measures are designed with a user-focused approach, that relevant design rules are aligned with the attributes of building users, that the user profile within the building is identified, that the number of users is quantified, and that the safety measures needed to be taken are compatible with the characteristics of the users.

Regarding users, buildings with the highest risk factors are those where sleep activity takes place and those which house users with limited mental and physical capabilities. The risks that impede a safe escape from fire include being elderly or a child, being under the influence of alcohol, having a disability, and the building being crowded.

In situations where the physiological, psychological, and emergency behavior of users particularly affect building usage conditions, it is essential that fire evacuation planning be aligned with the characteristics of the building and its users. This is especially important in hospitality outlets where sleeping activity takes place; in inherently crowded buildings frequented mostly by the elderly, such as places of worship, healthcare facilities, and care homes; in nurseries and kindergartens where most of the users are children; in permanently occupied residential buildings; and in buildings with users of varying characteristics, such as correctional facilities.

It is not possible to change the characteristics of the determined user group. For example, in a building:

- The presence of users working in unsupervised areas
- Use of the building by users who are not familiar with the building
- People with disabilities (including mobility impairment, hearing or visual impairment, etc.), young children or babies in nurseries, people with special needs, or people who may have another reason for not being able to leave the building quickly, such as the elderly
- Factors such as the building being open to night use and the presence of sleeping activity are defined as factors that cannot be changed or improved and are due to basic requirements

However, factors related to the fire in the building and the way the building affects the fire can be changed, corrected, and improved. For example, smoke from a fire contains toxic gases that are harmful to humans. A fire in a building produces dense black smoke, obstructs vision, causes great difficulty in breathing, and can block escape routes. It is important that escape routes and other fire safety measures are adequate to enable people to escape to safety before the fire traps them in the building.

In conclusion, the identified risk levels represent the fundamental elements that should be considered in the development and implementation of fire safety strategies as a critical component of risk analysis. Defining each category of user-related risks and conducting comparative analyses of these elements will contribute to improving evacuation processes and enhancing the effectiveness of fire safety practices.

The primary goal of future studies should be to examine these risk classifications in detail and to develop practical, application-oriented recommendations.

ETHICS: There are no ethical issues with the publication of this manuscript.

PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FINANCIAL DISCLOSURE: The authors declared that this study has received no financial support.

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