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PASSIVE FIRE SAFETY MEASURES IN INDUSTRIAL BUILDINGS AND A CASE STUDY

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IN ARCHITECTURE DEPARTMENT

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ETHICAL STATEMENT

I at this moment declare that in this thesis study, I prepared the thesis writing rules of Gazi University Graduate School of Natural and Applied Sciences;

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Merve AKÇA

07/07/2025

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(M. Sc. Thesis)

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ABSTRACT

Due to the high presence of hazardous materials and human density in industrial buildings, it is necessary to investigate passive fire safety measures, as active fire precautions alone will be insufficient, and it is important to guide architectural design in new industrial buildings based on evaluations, regulations, and simulations. Increasing consumption demand due to population growth in the world and in our country has increased the need for production; this situation has caused production areas such as industrial facilities to become more functional. Industrial buildings are complex facilities where continuous production is carried out and where machinery and equipment that pose a fire risk due to electrical overloading are actively used. Due to these characteristics, it has become imperative to develop comprehensive strategies for fire safety in such buildings. Passive fire safety measures, such as planning safe escape routes and creating fire compartments in the architectural design and implementation phases of industrial buildings, significantly reduce the risks that may occur during a fire. In this context, the aim of this thesis is to examine the national and international regulations and standards that play an active role in the architectural design process of industrial buildings, to investigate passive protection measures for fire safety, and to evaluate the evacuation safety of a building selected as a case study. In the study, a Printing Service Building planned to be constructed in Ankara was selected as a case study; evacuation times were analyzed using Pathfinder performance-based evacuation simulation, and a general evaluation was made based on the findings obtained. In this context, passive measures that can be taken to increase fire safety in industrial buildings during the design phase are discussed from an architectural point of view. As a result, it has been revealed that passive systems have critical importance among the protective measures taken against fire in industrial buildings.

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Key Words:	:	Industrial buildings, fire, passive fire safety measures, escape routes, evacuation, simulation
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ENDÜSTRİYEL BİNALARDA PASİF YANGIN GÜVENLİĞİ ÖNLEMLERİ VE BİR VAKA ÇALIŞMASI

(Yüksek Lisans Tezi)

Merve AKÇA

GAZİ ÜNİVERSİTESİ

FEN BİLİMLERİ ENSTİTÜSÜ

Temmuz 2025

ÖZET

Dünya genelinde ve ülkemizde, nüfus artışına bağlı olarak yükselen tüketim talepleri, üretim ihtiyacını da artırmış; bu durum endüstri tesisleri gibi üretim alanlarının daha işlevsel hale gelmesine neden olmuştur. Endüstri binaları, sürekli üretimin gerçekleştirildiği, elektrik yüklenmesi nedeniyle yangın riski taşıyan makine ve ekipmanların aktif olarak kullanıldığı, karmaşık tesislerdir. Bu özellikleri nedeniyle, bu tür yapılarda yangın güvenliği için kapsamlı stratejilerin geliştirilmesi zorunlu hale gelmiştir. Endüstri binalarının mimari tasarım ve uygulama aşamalarında, güvenli kaçış yollarının planlanması, yangın kompartımanlarının oluşturulması gibi pasif yangın güvenlik önlemleri, yangın anında oluşabilecek riskleri önemli ölçüde azaltmaktadır. Bu çerçevede, bu tezin amacı; endüstri binalarında mimari tasarım sürecinde etkin rol oynayan ulusal ve uluslararası yönetmelik ile standartları incelemek, yangın güvenliğine yönelik pasif koruma önlemlerini araştırmak ve örneklem olarak seçilen bir binanın tahliye güvenliğini değerlendirmektir. Çalışmada, Ankara'da yapılması planlanan bir Matbaa Hizmet Binası örneklem olarak seçilmiş; Pathfinder performans tabanlı hareket simülasyonu kullanılarak tahliye süreleri analiz edilmiş ve elde edilen bulgular doğrultusunda genel bir değerlendirme yapılmıştır. Bu kapsamda, endüstri binalarında tasarım aşamasında yangın güvenliğini artırmaya yönelik alınabilecek pasif önlemler mimari açıdan ele alınmıştır. Sonuç olarak, pasif sistemlerin, endüstri binalarında yangına karşı alınan koruyucu önlemler arasında kritik bir öneme sahip olduğu ortaya konulmuştur.

Bilim Kodu	:	80136
Anahtar Kelimeler	:	Endüstri binaları, yangın, pasif yangın güvenlik önlemleri, kaçış yolları, tahliye, simülasyon
Sayfa Adedi	:	107
Danışman	:	Prof. Dr. Füsun DEMİREL

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CONTENTS

Page

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

Figure **Page**

LIST OF IMAGES

Image **Page**

SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used in this study are presented below, along with their explanations.

Symbols	**Explanations**
cm	Centimeter
min	Minute
m	Meter
m2	Square meter
mm	Millimeter
s	Second

Abbreviations	**Explanations**
ASET	Available Safe Evacuation Time
NFPA	National Fire Protection Association
RSET	Required Safe Evacuation Time
TRRFP	Turkey’s Regulation on Fire Protection
TSE	Turkish Standards Institute

1. INTRODUCTION

With the advancement of technology and transportation, the Industrial Revolution emerged in the 18th century, giving rise to a new type of structure that enabled organized production activities: industrial buildings. These structures are typologically distinct, as they are characterized by high energy consumption and elevated fire risks, and serve as sites where production is carried out through human labor. Industrial facilities are critical production centers that play a key role in a nation's economic growth and development. By transforming raw materials into value-added products, these buildings support numerous sectors, including industry, energy, food, and technology. Thus, they hold not only economic importance but also strategic significance in terms of structural safety. Ensuring the uninterrupted and safe continuation of production processes necessitates effective collaboration between the disciplines of engineering and architecture.

From a historical perspective, the concentration of production-oriented structures within urban areas has contributed to major city fires and industrial disasters. The Crystal Palace, built in 1851 as a symbol of iron-and-glass technology, was entirely destroyed by fire in 1936. This event represented not only the loss of an iconic structure of the era but also came to symbolize the structural vulnerabilities related to fire safety in post-industrial architecture (Stamp, 2007). Similarly, the Triangle Shirtwaist Factory fire in New York in 1911, in which 146 workers lost their lives, has been documented as a tragic example of the absence of passive fire protection measures in industrial workplaces (Cornell University, 2003). Even earlier, the Great Fire of London in 1666 destroyed much of the city and demonstrated the devastating consequences of flammable building materials and unregulated urban development. Such catastrophes affected not only the physical environment but also had far-reaching impacts on production chains, the labor force, and long-term economic continuity (Franco, Chelleri, 2019).

Image 1.1.a. Crystal palace fire,1936 (URL-1)
b. Triangle Shirtwaist Factory fire, 1911 (URL-2)

Fires are among the most severe threats to human life, and fire safety constitutes an essential component of the basic human need for security. Industrial development is accompanied by increased energy consumption, and statistics show a direct correlation between per capita energy use and casualties or property loss resulting from fire incidents. For instance, countries with the highest per capita energy consumption—the United States, Canada, and the United Kingdom—also report the highest annual death rates due to fire compared to other nations. This suggests that as technology progresses and industrial density increases, the frequency and impact of fire incidents are also likely to rise. Therefore, it is imperative to continuously review and improve existing fire safety measures at both national and international levels (Demirel, Başdemir, 2010).

The second part of this study presents a literature review. Although fire safety measures should be considered at the initial stage of design, most universities offering design education in Turkey do not assign sufficient attention or importance to this issue. The selection of this thesis topic aims to contribute to this underexplored area within architectural area.

The third part examines fire safety measures in industrial buildings. Safe evacuation is defined as the removal of building occupants in the event of an emergency (Chow et al., 2006). Such emergencies may include natural events like storms or tsunamis, which affect large areas, or localized dangers such as fires or terrorist attacks. Even when the occupant load of a building is low, being trapped inside may pose a serious threat (Satır et al., 2021). Therefore, buildings—particularly industrial ones with high occupant densities—must be designed to enable effective evacuation. Image 1.1 illustrates a fire incident in an industrial building.

(a)

(b)

Image 1.2. a,b. Fire in an industrial building (URL-3,4)

Fire, which is a potential hazard in any environment where flammable materials, energy, and oxygen are present, is perceived as a more critical risk in industrial enterprises. The risk of fire in industrial facilities arises primarily from energy sources used for production purposes, defective electrical installations, sparks generated as a result of static electricity on surfaces heated by friction, chemical substance explosions, uncontrolled spread of controlled combustion, and occupational accidents. In this regard, passive fire safety measures are of great significance.

National and international regulations play a key role by guiding architects and engineers in implementing both passive and active fire safety measures. In all developed countries, governments have assumed responsibility for ensuring the safety of their citizens against fire. The necessary regulations are enforced through legislation. In the fourth chapter of the thesis, comparative analyses were conducted by reviewing our country's regulations, the British Regulations and Standards from Europe, and the NFPA 101 Life Safety Code from the United States. Following the comparative analyses, performance criteria were defined.

In the fifth chapter of the study, a case study was carried out. In this context, the Pathfinder program used in the case study provides information on how long it would take to evacuate the building in case of fire and what the potential obstacles may be, taking into account the physical characteristics of the building (floor plans, stairs, elevators, etc.) and the behavior of the occupants (walking speed, disability status, compliance with evacuation routes, etc.). Pathfinder is a user-based egress and human movement simulation tool (Thunderhead Engineering Consultants, 2022). It uses advanced algorithms and modeling techniques to simulate the movement of large groups of people in complex environments. It can be used to analyze a wide range of scenarios, including evacuation scenarios, crowd flow, crowd density, and occupant behavior (Akça, Ceylan, Demirel, 2023).

All over the world, the rapid development of computer models that evaluate the life safety of individuals inside buildings—in parallel with advancements in technical knowledge and hardware capabilities—has had a significant impact on reducing fatalities caused by fire. The diversity of simulation models that evaluate building evacuation in emergencies by prioritizing human behavior continues to expand rapidly today (Gültek, 2005). Emergency escape simulation programs are used to predict how to evacuate a building or facility in the event of fire, earthquake, or other emergencies, and to ensure that people can safely exit buildings under such conditions. These programs are widely preferred, especially for buildings with large occupant capacities, such as large commercial buildings, stadiums, airports, hospitals, and schools. Thanks to these programs, it is possible to predict optimal evacuation strategies and to determine in advance the appropriate actions to take in emergencies. In addition, with the integration of emergency escape simulation programs into the design and construction processes, many potential problems can be prevented before any danger occurs. Time and financial resources can be saved thanks to passive measures that can be implemented before harm is done (Akça, Ceylan, Demirel, 2023). There are many programs available for fire simulations. Various evacuation simulation software programs—such as Pathfinder, MassMotion, FDS+EVAC, Building Exodus, STEPS, and Simulex—are widely used. However, in this study, the performance-based simulation software 'Pathfinder' was preferred due to its user-friendly interface, which enables researchers to obtain comprehensive quantitative and qualitative data on evacuation route analysis and occupant movement during fire emergencies (Safari et al., 2024).

In the final section of the study, the data were analyzed, and solutions were proposed.

1.1. Defining the Problem

The high density of hazardous materials and occupants in industrial buildings poses a major problem in terms of ensuring fire safety and the safe evacuation of users. In architectural design, passive fire safety measures ensure the safety of life and function in the building during the period between the moment the ignition starts and the moment the fire becomes uncontrollable. In this context, architects have important duties to ensure fire safety in industrial buildings.

1.2. Purpose of Research

This research aims to examine the national/and international regulations and standards that play an active role in the architectural design of industrial buildings, to investigate passive fire safety measures implemented for fire safety, and to evaluate the fire evacuation performance of the building selected as a case study through a fire simulation program.

1.3. Scope, Content, and Limitations of Research

In this study, fire safety measures in buildings are limited to industrial buildings. When designing fire safety in industrial buildings, it is necessary to coordinate with multiple disciplines (mechanical, electrical, static, etc.). The primary goal for fire protection of buildings, based on architectural design, is to create passive protection systems. The purpose of passive protection is to reduce the use of active systems by minimizing the use of energy resources and construction costs that cause environmental pollution. These systems should be used to support architectural components and reduce energy consumption. In cases where architectural components cannot be properly designed, active systems must assume this role, which may be inadequate. Within the limits of this thesis, hydrocarbon fires and active protection systems were excluded from the scope, and solutions were developed within the framework of passive fire safety.

1.4. Significance of Research

Industrial buildings are high-risk areas in terms of fire safety. Fire protection is divided into active and passive protection: active protection prevents the accumulation of smoke and toxic gases to allow occupants to reach a safe place, while passive protection allows the evacuation of occupants from buildings designed in accordance with fire safety standards to safe areas within appropriate timeframes and distances. Active protection and passive protection work together. However, if active protection fails due to any problem, passive protection continues to fulfill its function. This research clearly demonstrates the importance and necessity of passive fire safety measures in industrial buildings, given the high density of hazardous materials and occupants.

1.5. Research Method

In the thesis study titled 'Passive Fire Safety Measures in Industrial Buildings and a Case Study', research techniques and methods are used to evaluate whether the data obtained are appropriate in the context of regulations and standards, and architectural suggestions and solutions are presented in light of this information. First, the concepts addressed in industrial buildings in the literature, national and international standards, and regulations are explained. To put the theoretical knowledge into practice, a printing service building to be constructed in Ankara was selected as a case study. Fire safety was tested using the performance-based Pathfinder motion simulation program and evaluated in accordance with Turkish regulations (TRRFP). Evacuation times were analyzed with Pathfinder motion simulation, and a general evaluation was made based on the data obtained.

1.6. Research Question and Hypothesis

Main questions of the research:

- Are passive fire safety measures necessary and sufficient for fire safety in industrial buildings?
- What are the relevant passive design principles in industrial buildings?

Sub-questions of the research:

- What are the sources that cause fire outbreaks in industrial buildings?
- What are the relevant national and international legislations in industrial buildings?

- What is the importance of fire evacuation simulations in industrial facilities?

Hypothesis of the research:

It is necessary to impement passive fire safety measures for fire safety in industrial buildings.

Research keywords:

Industrial buildings, fire, passive fire safety measures, escape routes, evacuation, simulation. Figure 1.1 shows a schema of the word associations for key industrial buildings.

Figure 1.1. Keywords schema

Figure 1.2 shows the flowchart of the thesis from the determination of the problem to the result.

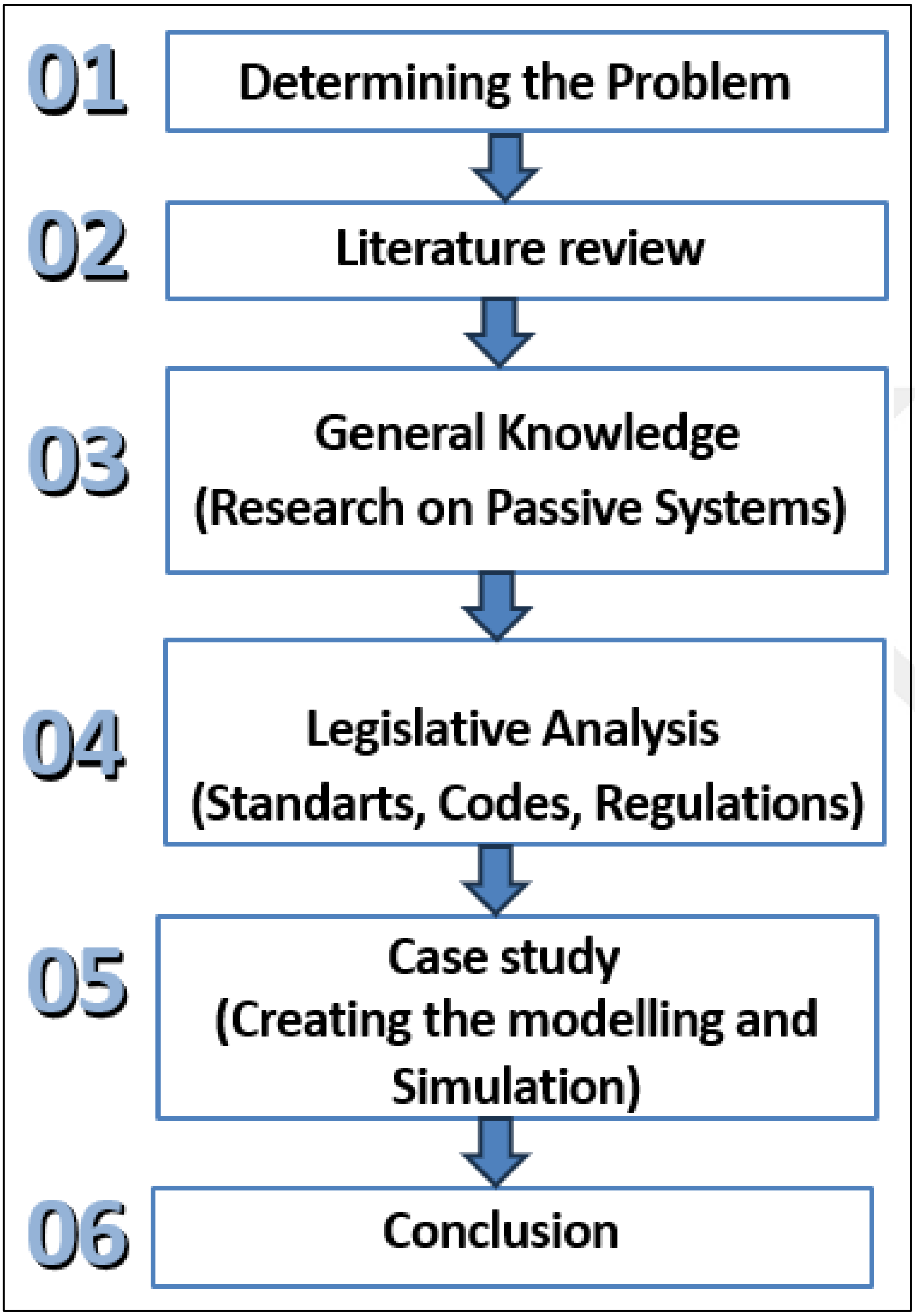


Figure 1.2. Thesis flow diagram

2. LITERATURE REVIEW

The thesis is a unique study in the literature as it is the first study on Passive Fire Safety Measures in Industrial Buildings. The following sources were examined in detail within the framework of the master's thesis on industrial buildings. Literature review consists of three sections. Figure 2.1 shows the proportion of studies surveyed in literature.

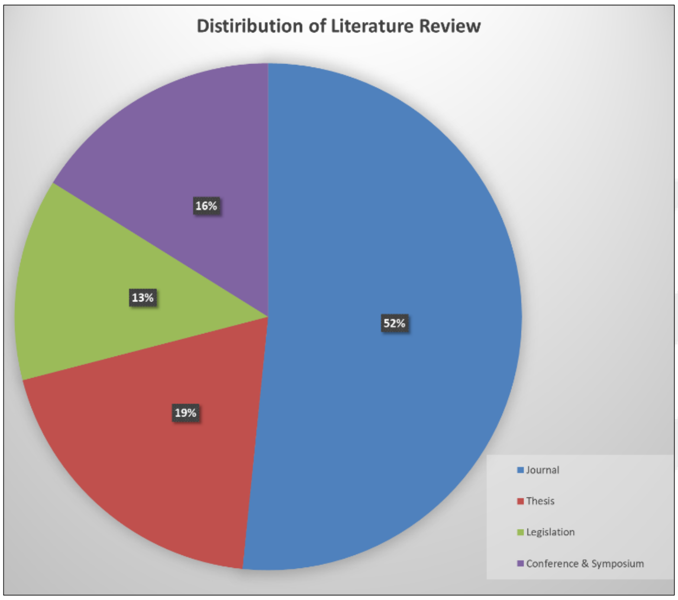


Figure 2.1. Distiribution of literature review

2.1. National and International Legislation Related to Fire Safety

The first section is national and international legislation related to fire safety. In our country, there is a Turkey's Regulation on Fire Protection (TRRFP), which entered into force in 2002 and is still valid today by making several regulations. The fire test devices referred to by the regulation are made within the framework of various standards determined by the Turkish Standards Institute (TSE).

There is legislation as The Building Regulations 2010, for structural designs in England and Wales. In the UK, building regulations are statutory instruments or statutory regulations that aim to guarantee the implementation of the policies outlined in the pertinent law. The majority of building projects in the UK require approval from building rules (Hm Government, 2021).

There is a National Fire Protection Association (NFPA) code in the United States. NFPA standards are regulated by evaluating fire disasters and creating statistics. In all sections of the standard, a comprehensive standard has been prepared by regulating the articles containing performance-based design, as well as the traditional provision-based articles. NFPA 101 Life Safety Code Chapter 40 includes Industrial Occupancies (NFPA, 2018).

2.2. Studies Related to Fire Safety in Industrial Buildings

The second section is studies related to fire safety in industrial buildings. There is a lack of literature in the field of fire protection of industrial facilities. Studies on industrial facilities include examination of an industrial facility and its causes, passive fire safety measures, evaluation of fire risks that may arise in industrial facilities, examination of an industrial facility within the framework of regulations, the importance of fire safety in the building design and construction process, the importance of national standards and regulations. Studies on these subjects are included.

2.2.1. Studies conducted in Turkey regarding industrial buildings

In the study titled Design and Application Principles of Passive Firestop Systems in Industrial Facilities prepared by Aycı, the design principles for the use of passive firestop systems in industrial and energy facilities were evaluated. Aycı examined the design principles of passive firestop systems in industrial facilities in detail. He concluded that passive firestop systems are one of the measures taken to protect industrial facilities from fire (Aycı, 2021).

Çataklı conducted a study entitled Analysis of Fire Safety Measures in Thermal Power Plants: The Case of Zonguldak Eren Energy. In this study, fire safety measures in buildings are limited to industrial structures. Thermal power plants are structures with a high fire risk in the context of hazardous material storage and the way they work. High fire risk sections have been examined within the scope of transportation, storage, preparation, incineration facilities, power generation facilities and auxiliary enterprises (Çataklı, 2022).

Işık conducted a study entitled Fire hazard in textile factories: fire prevention and safety measures. One of the primary textile factories in Sakarya was visited as part of the fieldwork for this study. Records pertaining to factory fires from the past to the present were examined, the causes of the fires were identified, employee interviews were used to gather information, a case analysis was carried out to assist in resolving similar issues in the present, and appropriate actions were taken in light of the information gathered (Işık, 2022).

Uçar conducted a study entitled Fire safety in industrial facilities and assessment of fire safety in a plugged cable manufacturing facility. In Uçar's thesis study, a legislation checklist was created in line with the "Regulation on Fire Protection of Buildings" in an industrial facility that produces plug-in cables, and the necessary precautions to be taken for inappropriate criteria were specified. The results of risk analysis were examined and the technical, administrative, etc. necessary to reduce them. The measures to be taken are explained in detail (Uçar, 2019).

İbik conducted a study entitled Use of Roof and Facade Cladding Materials in Industrial Facilities in Terms of Fire Safety. In his article, İbik states that the building materials used as coating materials in industrial facilities, especially on the roofs and facades of the facility, and the structural elements with or without load-bearing properties created by these materials, play a decisive role in the fire safety of the roofs and facades that form the outer shell of the facility and therefore the protection of the entire facility from fire (İbik, 2013).

Rojhat conducted a study entitled An Assessment of Fire Risks That May Arise in Industrial Facilities: The Case of Kocaeli. In Rojhat's study, the causes of the fire were determined. Examining fires and sharing them with stakeholders is very important in preventing fires that may break out for the same or similar reasons in the future. The Ministry of Labor and Social Security, universities and non-governmental organizations should conduct detailed studies on the causes and precautions of fire, especially for industrial facilities, and organize training and information meetings.

2.2.2. Studies conducted in the world regarding industrial buildings

TÜYAK published a proceedings book titled Fire Safety and New Technologies in Industrial Facilities in 2019. This book contains various important articles on fire safety measures that can be taken in industrial facilities (TÜYAK, 2019).

Umoh conducted a study entitled An Assessment of Fire Safety Provisions in Industrial Buildings in Nigeria. This study assessed Nigerian industrial buildings' fire safety features. This study's primary goal was to evaluate the degree of fire safety and control needs in a paint factory (Umoh, 2009).

Askaripoor et al. conducted a study entitled The role of the implementation of national building regulations in the fire safety improvement of industrial structures. Askaripoor et al. (2016) evaluated how national building codes affect fire risk reduction in industrial facilities. Using the FRAME method, they assessed fire risks in a power plant control room, highlighting the critical role of fire safety in building design and construction (Askaripoor, 2016).

Athapaththu et al. conducted a study entitled Effective fire safety planning for industrial buildings: A literature review. Athapaththu et al. (2013) proposed a conceptual model for fire safety planning in industrial buildings through a detailed literature review. Their findings revealed that many facilities, including factories, often neglect regular fire drills (Athapaththu et al, 2013).

Dârmon conducted a study entitled Probabilistic methods to assess the fire risk of an industrial building." Procedia Manufacturing. Dârmon (2020) stated that a probabilistic approach should be taken into account in order to evaluate the risks and consequences associated with a fire incident in an industrial building. The event tree method was used to evaluate the frequency and associated consequences of a fire event in an industrial building (Dârmon, 2020).

2.3. Studies Conducted Using Simulation in terms of Method

In the last section, studies using simulation were examined in terms of method. In these studies, fire and escape simulations were used as methods. Since I will evaluate the evacuation process with a simulation in case study, it will shed light on my study in terms of which data I will evaluate in the simulation.

Han et al. conducted a study entitled Pathfinder-based simulation and optimisation of personnel evacuation modelling of a shopping mall. Han et al. conducted a study using Pathfinder to simulate and optimize staff evacuation in a shopping mall in Xi'an's Weiyang District. They first analyzed crowd flow and distribution during peak hours using queuing theory, then simulated evacuation scenarios to examine congestion patterns (Han et al, 2021).

Spearpoint conducted a study entitled the impact of pre-evacuation on evacuation times in the Simulex. This study examines how the Simulex model's pre-evacuation time distributions affect occupant's travel times and, consequently, their evacuation times. (Spearpoint, 2004).

Zhang et al. conducted a study entitled Simulation-based route planning for pedestrian evacuation in metro stations: A case study. Zhang et al. (2016) emphasized that route planning notably enhances evacuation efficiency. Their approach offers practical insights for optimizing pedestrian evacuation, contributing to both safety and cost-effectiveness in subway system design (Zhang et al, 2016).

Benseghir conducted a study entitled Modelling emergency evacuation from an industrial building under spreading fire using a social force model with fire dynamics. Benseghir developed a crowd dynamics model for emergency evacuation in industrial buildings during a spreading fire. Findings indicate that factors like fire growth rate, crowd density, and exit width significantly influence evacuation time. The proposed model can be used to simulate the efficiency of the evacuation process from an industrial building and thus improve the industrial design to increase the safety level (Benseghir, 2021).

Chanthakhot conducted a study entitled Integrated IEW-TOPSIS and fire dynamics simulation for agent-based evacuation modeling in industrial safety. Chanthakhot suggested a new simulation model that combines fire dynamics simulation with agent-based evacuation simulation proposed to evaluate the impact on the behavior of evacuees (Chanthakhot, 2021).

Figure 2.2 shows a scheme of grouping literature review. The relationship between the groupings made, primary and secondary sources were expressed graphically. Table 2.1. shows literature research table.

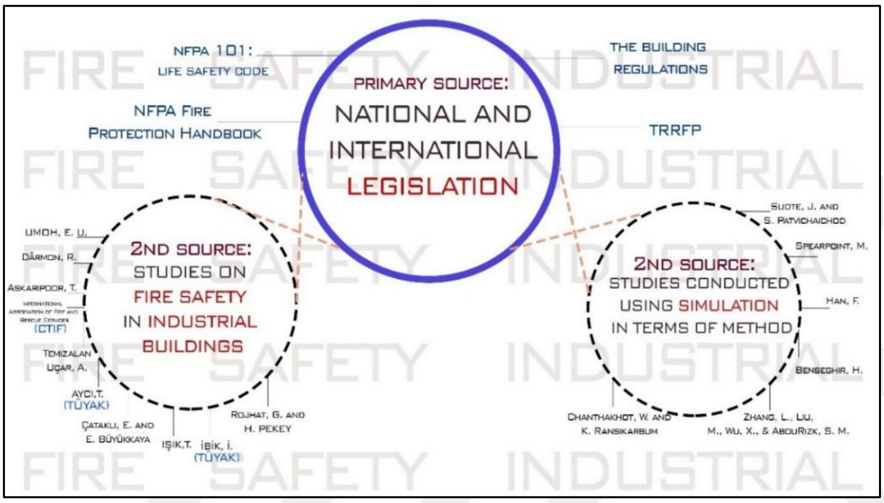


Figure 2.2. Scheme of grouping literature review

Table 2.1. Literature review table

No	Author/Authors	Year	Place of Publication	Type of Study	Name of Publication
1	Aycı T.	2010	TÜYAK Fire Engineering Journal	Article	Design and Application Principles of Passive Fire Stopping Systems in Industrial Facilities
2	Han, F., et al.	2021	IOP Publishing	Conference Series	Pathfinder-based simulation and optimisation of personnel evacuation modelling of a shopping mall

Table 2.1. (Continued) Literature review table

No	Author/Authors	Year	Place of Publication	Type of Study	Name of Publication
3	Akça M., Ceylan F., Demirel F.	2023	Architecture and Fire Symposium Proceedings Book, pp 85-94, 2023	Symposium	Analysis of Escape Route Simulation Programs Specific to Educational Buildings and a Case
4	Bakırcı, E., Karatop, B., and Bayındır, S.	2019	Natural Hazards and Environment Journal	Article	Comparison of Statistical Data Types for the Formation of Fire Strategies with Turkey (Istanbul Province Example) and Selected Countries
5	Başdemir, H. and F. Demirel	2010	Politeknik Journal	Article	A literature review on passive fire safety measures in buildings
6	Bingöl, C	2023	Gazi University Institute of Science	Master's Thesis	Fire statistics in comparison within İstanbul (Turkey), London (England) and New York City (United States of America) context

Table 2.1. (Continued) Literature review table

No	Author/Authors	Year	Place of Publication	Type of Study	Name of Publication
7	Hm Government, Great Britain.	2021 ed.			The Building Regulations 2010
8	Kılıç, A. and K. Beceren	1999	IV. National Plumbing Engineering Congress and Exhibition	İzmir, TMMOB Chamber of Mechanical Engineers	Fire safety in architectural design
9	National Fire Protection Association	2018		Legislation	NFPA 101 Life Safety Code
10	National Fire Protection Association	2008, 20th ed.		Legislation	NFPA Fire Protection Handbook
11	Spearpoint, M.	2004	Journal of Fire Protection Engineering	Article	The effect of pre-evacuation on evacuation times in the Simulex model
12	Özdamar, E. D.	2020	Gazi University Institute of Science	Master's Thesis	Passive fire safety measures in underground metro stations: investigation of evacuation process and a sample

Table 2.1. (Continued) Literature review table

No	Author/Authors	Year	Place of Publication	Type of Study	Name of Publication
13	Şengöz, M. C.	2018	Süleyman Demirel University Graduate School of Natural and Applied Sciences	Doctoral Thesis	Investigation of Electrical Fires and Risk Analysis with FMEA Method
14	Şimşek, Z.	2013	Uludağ University Graduate School of Natural and Applied Sciences	Doctoral Thesis	Modeling Method for Providing Fire Safety and Smoke Control in Healthcare Buildings
15	TMMOB Chamber of Chemical Engineers Istanbul Branch	2022		Article	Industrial Fires and Explosions 2022 Annual Report
16	Turkey, Council of Ministers	2015	Istanbul: Turkish Fire Protection and Education Foundation/Fire Protection Association	Regulation	Regulation on Fire Protection of Buildings

Table 2.1. (Continued) Literature review table

No	Author/ Authors	Year	Place of Publication	Type of Study	Name of Publication
17	TÜYAK	2023	Fire Safety and Technologies Journal	Article	Fire Engineering
18	Umoh, E. U.		Science And Technology	Article	An Assessment of Fire Safety Provisions in Industrial Buildings in Nigeria
19	Gültek, M.	2005	Gazi University Institute of Science	Doctoral Thesis	Legislative evaluation of shopping malls with atriums within the framework of fire safety and simulation of escape routes through sample projects
20	Godes, C. R	2024	Sustainability	Article	Optimizing Evacuation Efficiency in Buildings: A BIM-Based Automated Approach to Sustainable Design
21	Ng, C. M., & Chow, W. K.	2006	International journal on architectural science	Article	A brief review on the time line concept in evacuation. International journal on architectural science
22	Safari, M., et al.	2024	Buildings 2025	Article	Simulation of Fire Emergency Evacuation in a Primary School Based on Pathfinder Software.

Table 2.1. (Continued) Literature review table

No	Author/ Authors	Year	Place of Publication	Type of Study	Name of Publication
23	Satır, M. S. and A. Y. Topraklı	2021	Gazi University Faculty of Engineering and Architecture Journal	Article	Qualitative and quantitative analysis of fire evacuation risks of 18 historical mosques in Ankara-Altındağ region
24	Sujatmiko, W., Dipojono, H. K., & Soelami, F. N.	2014	Procedia Environmental Sciences	Article	Performance-based fire safety evacuation in high-rise building flats in Indonesia–a case study in Bandung
25	Kobes, M., Helsloot, I., De Vries, B., & Post, J. G.	2010	Fire Safety Journal	Article	Building safety and human behaviour in fire: A literature review
26	Yaman, M., Kurtay, C.	2021	ITU Journal of the Faculty of Architecture,	Article	Investigation on evacuation scenarios according to occupant profile in mosques through different fire regulations
27	Satır, M. S., & Topraklı, A. Y.	2020	Gazi University Journal of Science	Article	A review of evacuation of high-rise buildings. Gazi University Journal of Science Part B: Art Humanities Design and Planning

Table 2.1. (Continued) Literature review table

No	Author/ Authors	Year	Place of Publication	Type of Study	Name of Publication
28	Kuligowski, E. D.	2016	SFPE Handbook of Fire Protection Engineering	Article	Human Behavior in Fire
29	Yaman, M.	2025	International Journal of Built Environment and Sustainability	Article	Analysis of Exits in Fire Evacuation and Crowd Management in Multi-Functional Sports Halls
30	Wang, S. H., et al.	2015	Automation in construction	Article	Applying building information modeling to support fire safety management
31	Kobes, M., Post, J., Helsloot, I., & Vries, B. D.	2008	In Conference Proceedings FSHB	Article	Fire risk of high-rise buildings based on human behavior in fires. In Conference Proceedings FSHB
32	Kuligowski, E., et al.	2019	Fire Safety Journal	Article	A pre-evacuation database for use in egress simulations
33	Huo, F., Song, et al.	2016	Safety Science	Article	Experimental study on characteristics of pedestrian evacuation on stairs in a high-rise building

3. FIRE SAFETY PRECAUTIONS IN INDUSTRIAL BUILDINGS

3.1. General Knowledge and Ignition Sources of Industrial Fire

General knowledge about fire

Thanks to the fire safety measures to be taken in the building, current situation improvement suggestions are offered according to the fire load, hazard class, production method, material storage method and fire safety systems of the facility, thus ensuring the safety of life and property. Figure 3.1 shows fire safety elements.

Figure 3.1. Fire safety elements (URL-5)

Combustion is an exothermic chain reaction of flammable substances under certain conditions with the help of an ignition source with oxygen or other oxidizing gases (Figure 3.2). The increased heat at the end of the reaction allows the combustion to continue more vigorously. This physicochemical event continues its activities in a continuous cycle. If there is enough fuel in the environment, it spreads rapidly. All fuels must reach the gas form and meet with oxygen before combustion starts. The fuel diffuses through the air as a gas and forms a fast-burning mixture. When this mixture reaches the ambient ignition temperature, it ignites and begins to burn. A sparking electricity leak, a cigarette butt, a slight flame are external factors that accelerate ignition. All materials used in the building are fuel, which is a link in the combustion chain. As the speed of the chain reactions forming the combustion event increases, the severity of the fire also increases (Şimşek, 2013).

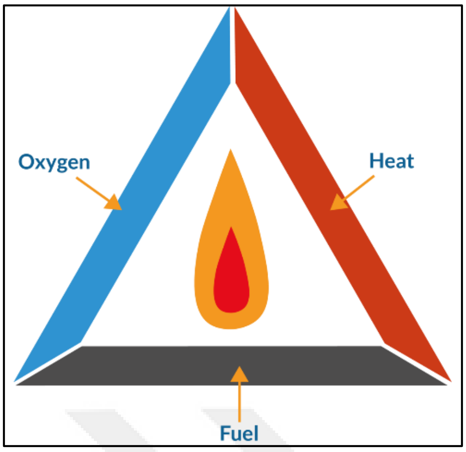


Figure 3.2. Combustion triangle (URL-6)

Unpredictable or unexpected heat sources cause a fire in the presence of air and flammable material. Reasons such as cigarette, lightning, friction, mechanical arc, heat source, arcs in electrical systems can be sufficient for the fire to start (Şengöz, 2018).

With the development of technology, people's daily lives have become easier, while the living space has been enriched with organic materials. This has caused a serious increase in the number of flammable and combustible materials that can cause a fire (Bakırcı, Karatop, and Bayındır, 2019).

The knowledge regarding the causes of fires is crucial for informing environmental and civil protection regulations, as well as for developing effective preventative strategies (Bingöl, 2023).

Definitions

In order to make the thesis and its constituent chapters clear and understandable, a definitions section is included. The definitions are the terms found in the Regulation on the Protection of Buildings from Fire and the National Fire Protection Association 101 Life Safety Code. The terms are arranged and explained in alphabetical order.

Building height: In the TRRFP, the lenght from the point where the building is leveled to the eaves level or the height stipulated in the zoning plan and this regulation.

Combustion: According to the definition made by NFPA 101 Life Safety Code, a chemical oxidation process that proceeds quickly enough to generate heat and, typically, light in the form of a flame or glow.

Escape (Fire) staircase: In NFPA 101 Life Safety Code and in the TRRFP , a staircase that can be utilized to quickly and safely evacuate building occupants in the event of a fire or other emergency, organized in a fire-proof manner and opening to a safe area at natural ground level (Image 3.1).

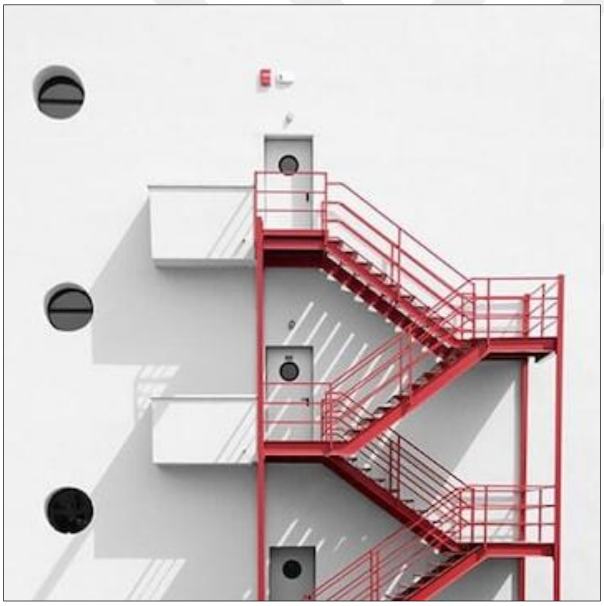


Image 3.1. Escape (fire) staircase (URL-7)

Escape distance: In the TRRFP, the length of the walkway that a user at the furthest point of standing in a space on any floor must take to the nearest floor exit.

Escape route: In the TRRFP, the entire unobstructed path from any point in the building to the street or alley at ground level, including exits from rooms and other isolated volumes, hallways and comparable passageways on floors, floor exits, ground floor staircases, and pathways leading to the building's final exit.

Exit Discharge: In NFPA 101 Life Safety Code, that section of an egress route between a public way and the exit's termination.

Fire Compartment: According to the definition made by NFPA 101 Life Safety Code, a section of a building that is completely surrounded by fire barriers, including the upper and base.

Fire Barrier: According to the definition made by NFPA 101 Life Safety Code, to prevent fire spread, a perpetual or partially interrupted membrane with rated fire-resistant openings is designed and constructed to meet specific fire resistance standards (Image 3.2).

Image 3.2. Fire barrier (URL-8)

Fire Scenario: In NFPA 101 Life Safety Code, a group of circumstances that specify how a fire starts, how combustion products propagate across a building or part of a building, how people react to fire, and how combustion products affect a building.

Fire zone (zone): It is defined in the TRRFP as in case of fire, the section whose warning and extinguishing measures are activated separately from the systems in other sections,

Fire breaker: It is defined in the TRRFP as a horizontally or vertically positioned element that stops the progress and spread of fire and smoke in the building for a specified period of time.

Fire wall: It is defined in the TRRFP as a vertical element that stops the progress and spread of fire for a specified period of time in cases where volumes with different fire loads must be separated between two buildings or within the same building,

Fire safety hall: In NFPA 101 Life Safety Code and in the TRRFP, a section to be built to hinder the passage of fire and smoke to escape stairs (Figure 3.3).

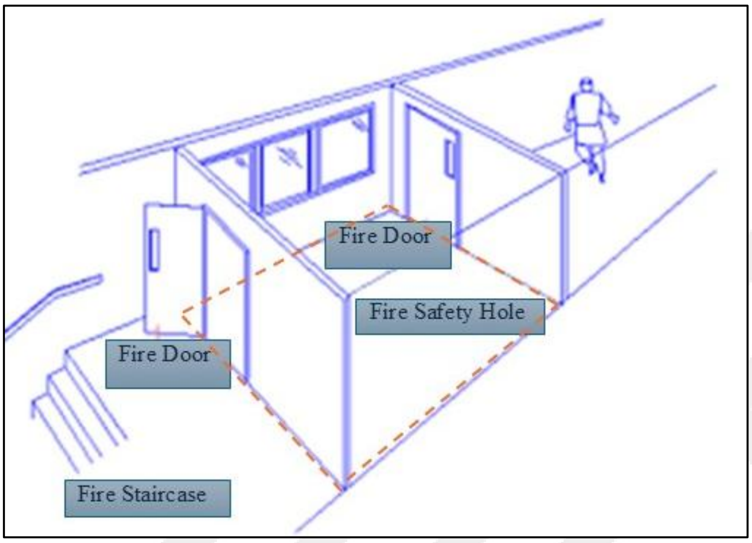


Figure 3.3. Fire safety hall (URL-9)

Fire door: In the TRRFP, a door, cover or shutter that provides circulation for users, air or objects in a structure and that will resist the passage of smoke, heat and flame for a certain period of time when closed (Image 3.3).

Image 3.3. Fire door (URL-10)

Fire compartment: In the TRRFP, an area within a building, including the ceiling and floor covering, separated into smoke and heat-proof areas with structural elements resistant to fire for at least 60 minutes on all sides.

Fire curtain: In the TRRFP, specially equipped barriers used to protect the object, product or substructure to be protected against fire or to prevent the spread of heat horizontally or vertically.

Fire evacuation project: In the TRRFP, the project in which the locations of escape routes, fire escapes, fire escapes, emergency elevators, fire cabinets, fire brigade water supply and intake nozzles and fire pumps are marked in color on the architectural project.

Fire Barrier Wall: In NFPA 101 Life Safety Code, a wall with a fire resistance rating that is not a fire wall.

General Industrial Occupancy: In NFPA 101 Life Safety Code, an industrial tenancy where regular, low-hazard industrial operations are carried out in conventionally designed facilities that can accommodate a variety of industrial processes.

Hazardous Material: In NFPA 101 Life Safety Code and in the TRRFP, a material or chemical that is categorized as either a health or physical threat, regardless of whether it is in a useful or trash state.

High Hazard Industrial Occupancy: In NFPA 101 Life Safety Code, an industrial space where high-hazard products, procedures, or contents are used for industrial operations.

Means of Egress: In NFPA 101 Life Safety Code, a continuous, unhindered path that connects any location within a building or structure to a public pathway. It is made up of three different and independent sections: the exit access, the exit, and the exit discharge (Figure 3.4).

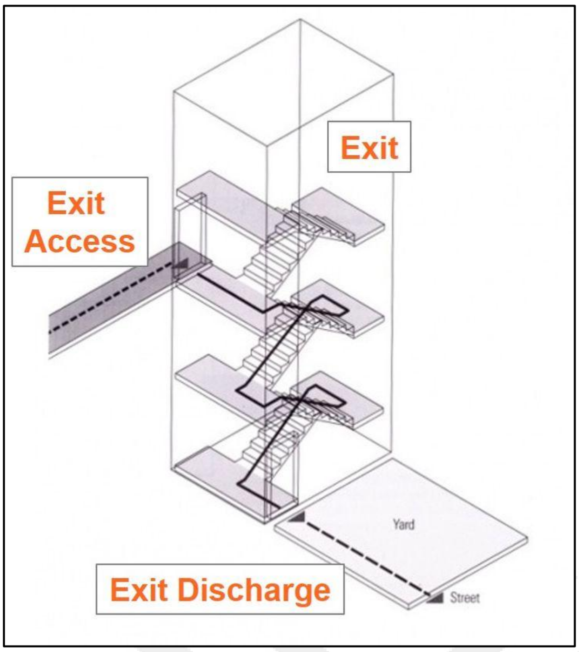


Figure 3.4. Means of egress scheme (URL-11)

Occupancy: In NFPA 101 Life Safety Code, the reason for the use or anticipated use of a building, other structure, or a portion of it.

Occupant load: In the TRRFP, the total number of people likely to be present in a building or a specific underlying part of a building at any one time.

One-way escape distance: In the TRRFP, the distance to the point at which persons within a space have an exit or an alternative means of escape in two directions, moving in only one direction.

Performance Criteria: In NFPA 101 Life Safety Code, threshold values on measuring scales derived from performance goals that can be measured.

Resistance to fire (resistance): It is defined in the TRRFP as the ability of a building component or element to withstand fire by maintaining its load carrying, integrity and insulating properties for a specified period of time,

Smoke Barrier: According to the definition made by NFPA 101 Life Safety Code, a membrane that is intended and built to prevent smoke from moving, either continuously or with discontinuities made by protected openings (Image 3.4).

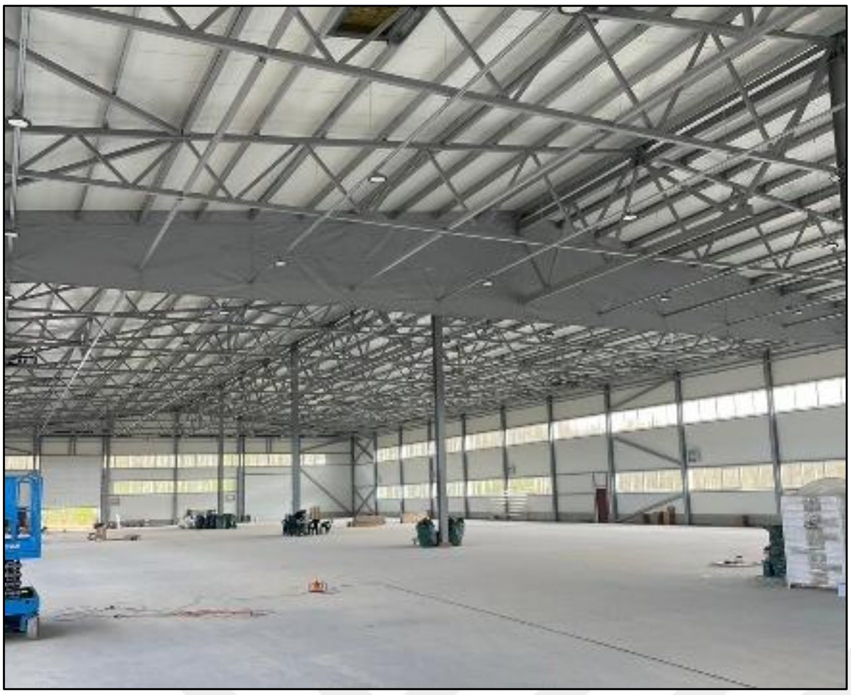


Image 3.4. Smoke barrier (URL-12)

Safety zone: In the TRRFP and in NFPA 101 Life Safety Code, the area where people evacuated from the building can wait safely outside the building.

Sprinkler system: It is defined in the TRRFP as an automatic system that sprays water to put out the fire, provide cooling and limit the developing fire until the fire brigade arrives (Image 3.5).

Image 3.5. Sprinkler system (URL-13)

Structure height: In the TRRFP, the total height of all constructed floors of the building, including basements, mezzanines and attic spaces.

User load coefficient: In the TRRFP, the expression of the area of use per person in buildings in square meters in m2/person.

Ignition sources of industrial fire

In fires and explosions where the ignition source is detected, those caused by electrical sparks come to the fore (Image 3.6). Lack of periodic maintenance and controls of electrical installations and violation of occupational safety rules in electrical work cause an increase in electrical fires. The fact that periodic checks of electrical equipment used in explosive atmospheres have not been carried out despite being mandatory can be considered as another problem area. Fires and explosions caused by electrical sparks are followed by those caused by mechanical sparks (Figure 3.5). In order to prevent fires and explosions caused by mechanical sparks, special precautions should be taken during the operation of equipment known to be a source of mechanical sparks and a work permit system should be implemented. The same applies to open flame fires. Fires and explosions caused by overheating are usually caused by the heating of soot in ventilation shafts (TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, 2023).

Image 3.6. Electricity leakage (URL-14)

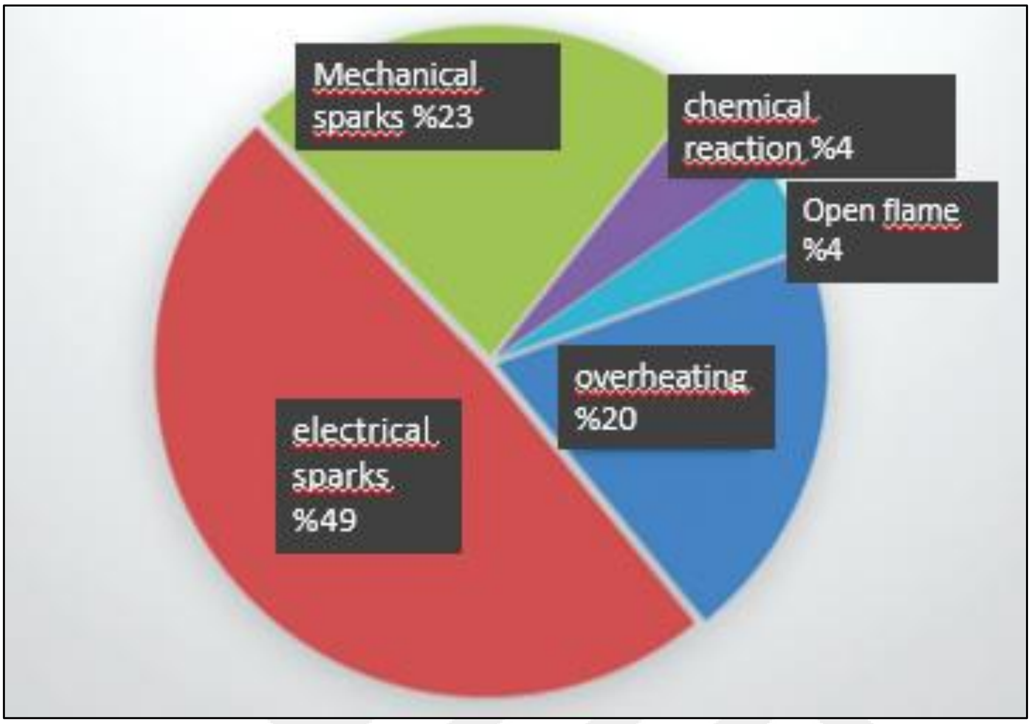


Figure 3.5. Ignition sources of industrial fires / explosions (TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, 2023)

3.2. Fire Statistic in Industrial Buildings

According to the Industrial Fires and Explosions 2022 Report published by the Kimya Mühendisleri Odası (KMO) Istanbul Branch in April, 587 industrial fires and explosions occurred in Turkey in 2022 (Figure 3.6). Of these incidents, 551 were classed as industrial fires, while 36 were industrial explosions. In these industrial fires and explosions, 22 workers died, and 139 people were injured. (Figure 3.7) (TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, 2023).

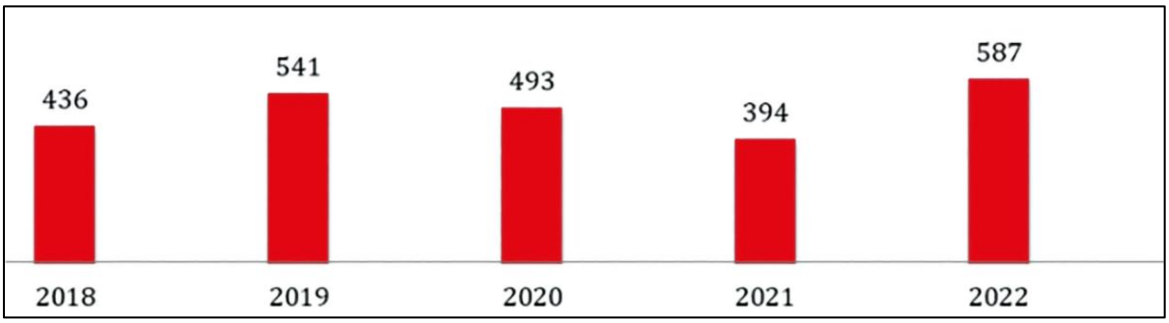


Figure 3.6. Comparison of the number of industrial fires and explosions in 2018-2022, (TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, 2023)

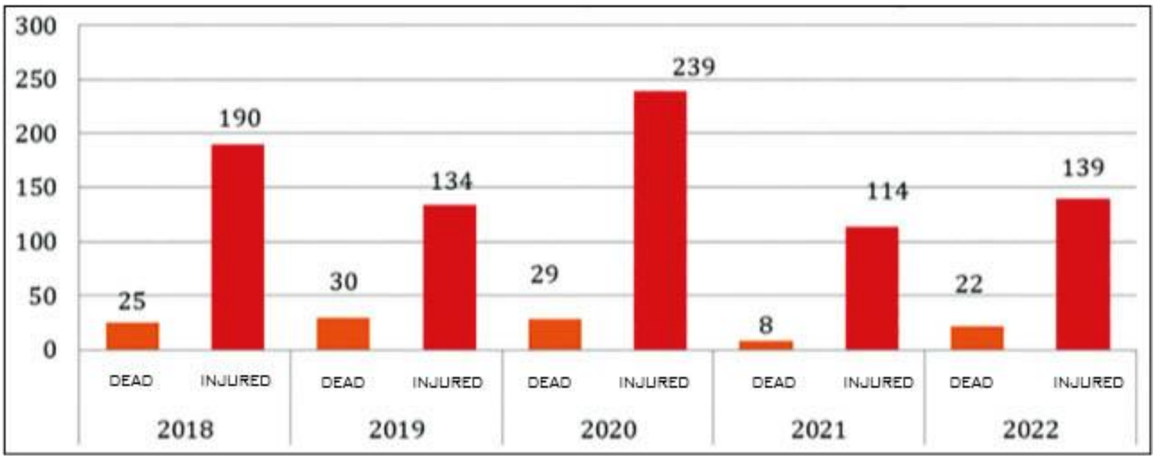


Figure 3.7. Number of deaths and injuries in industrial fires and explosions in 2018-2022 (TMMOB, 2022)

When the *sectoral distribution of industrial fires and explosions* is analyzed; “Metal”, “Textile”, “Wood, paper, furniture”, “Rubber and Plastic” sectors are concentrated. At least 73% of all fires and explosions occurred in these four sectors. The sector of approximately 30% of industrial fires and explosions could not be identified. Of the identified fires and explosions, 96 took place in industrial facilities producing in wood, paper and furniture (23%), 82 in metal (20%), 62 in textiles (15%), 63 in rubber and plastics (15%) and 57 in food (14%). The sector with the highest number of industrial fires and explosions was textile in 2018, metal in 2019, wood, paper and furniture in 2020, 2021 and 2022 (TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, 2023). Figure 3.8 shows the sectoral distribution of the number of industrial fires and explosions in 2018-2022.

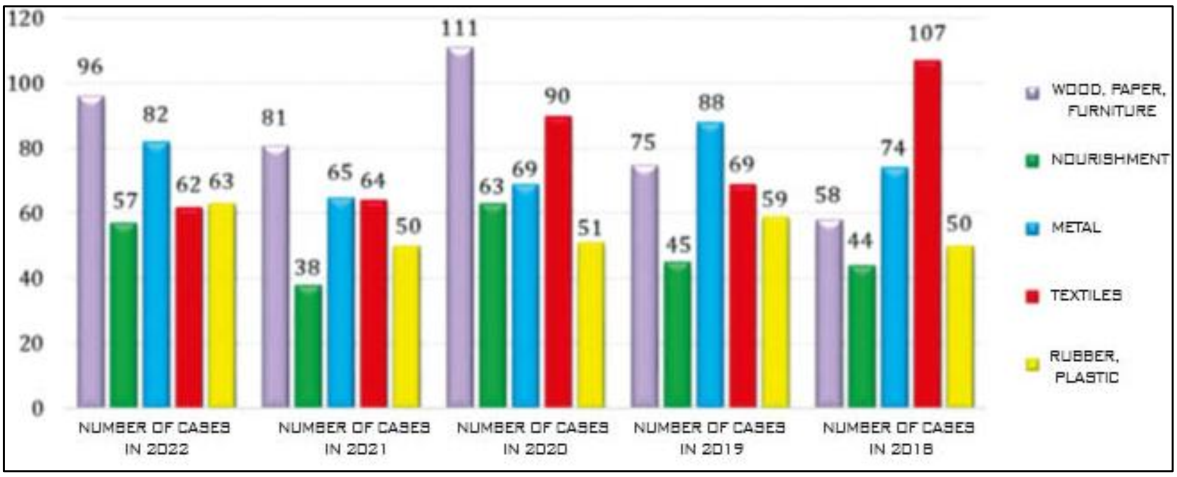


Figure 3.8. Sectoral distribution of the number of industrial fires and explosions in 2018-2022 (TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, 2023)

3.3. Fire Safety Design Principles in Industrial Buildings

Architects and engineers are the people who implement fire safety in accordance with TRRFP. Organizationally, they provide fire safety of the building with two systems, active and passive (Figure 3.9). Seeing all of them as a whole affects the design process positively.

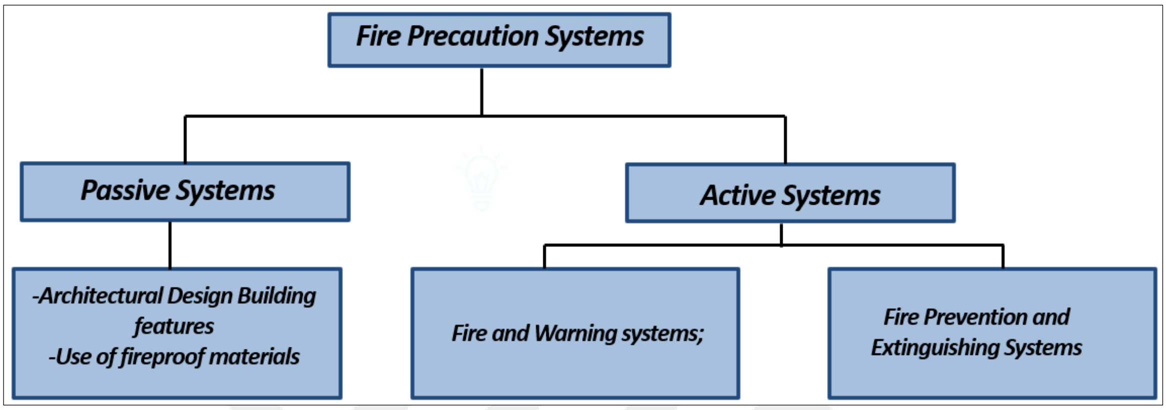


Figure 3.9. Fire precaution systems diagram

3.3.1. Passive systems

Passive systems include fire escapes, escape routes, installation shafts, pump rooms, fire compartments, fire breakers, water tanks and smoke evacuation chimneys. Especially passive systems are issues that affect the architectural design as a whole (Demirel, Başdemir, 2010).

According to Başdemir, Figure 3.10 constitutes the fundamental passive fire safety measures in industrial buildings (Demirel, Başdemir, 2010).

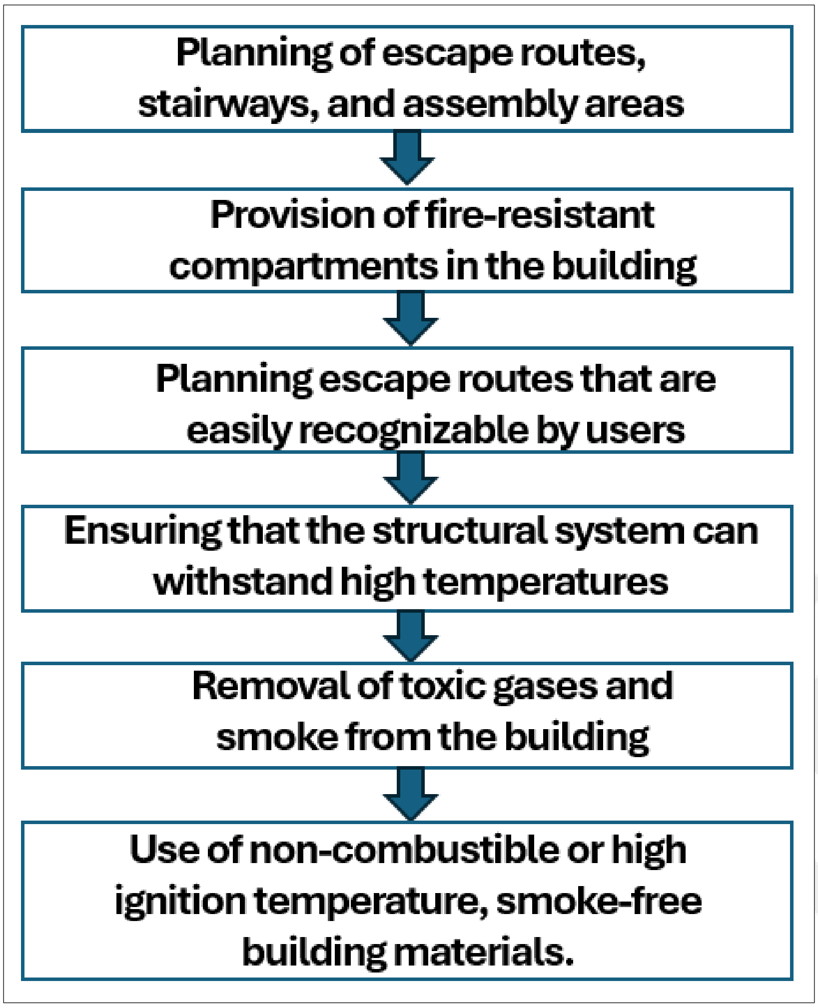


Figure 3.10. The fundamental passive fire safety measures in industrial buildings (Demirel, Başdemir, 2010)

Passive firestop systems are applied in various areas to prevent the progression of fire in industrial buildings. During fire design, a "fire compartmentation plan" is created by considering all fire prevention systems together; Passive firestop systems are applied in various areas to prevent the progression of fire in industrial buildings. During fire design, a "fire compartmentation plan" is created by considering all fire prevention systems together;

- Protecting passenger exit routes.
- Ensure adequate structural stability.
- Increasing the time, it takes for the fire brigade to enter the building and rescue the occupants.
- Confining the fire to the point of origin.

- Stopping the passage of fire and smoke without damaging assets and equipment in the other room.

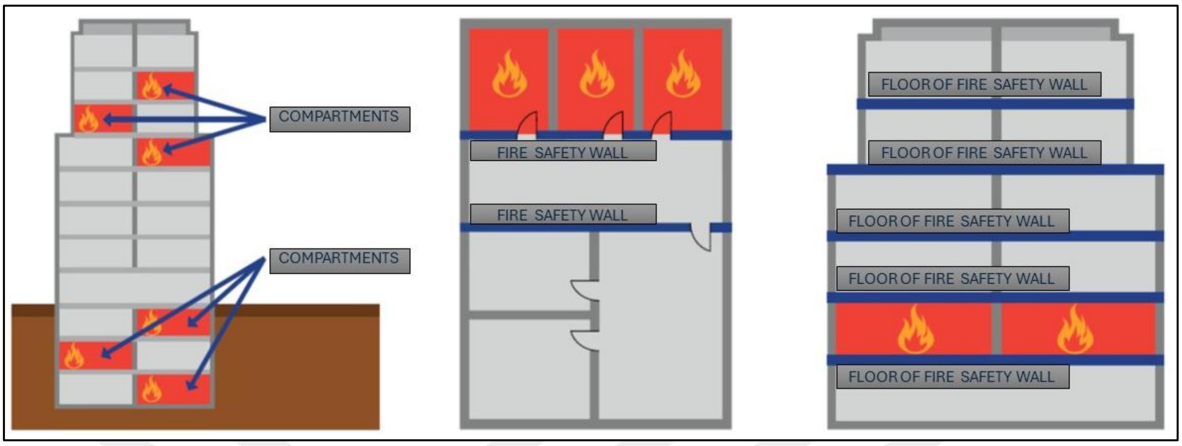


Figure 3.11. Fire compartmentation demonstration (Aycı, 2021)

Figure 3.11 shows fire compartmentation demonstration. A schematic representation of the horizontal and vertical compartmentation is given in figure 3.11. The walls marked in the figure 3.11 are called "fire walls" in literature.

Passive firestop systems are used at points where the integrity of fire walls specified in fire compartmentation has been compromised. When classified, the areas of application are generally divided into four main sections. These are: mechanical system penetrations, electrical system penetrations, joints and expansion joints, and curtain wall joints.

3.3.2. Active systems

Active systems are systems such as fire cabinets, sprinkler system, gas extinguishing system, stair pressurization, smoke evacuation system, detection and warning systems. They are energy- and finance-based systems that detect fire in buildings and aim to extinguish it as fast as possible (Demirel, Başdemir, 2010).

Active fire detection systems aim to ensure life safety by informing the users of the building with the help of various electrical installations during a fire, while the active stop system aims to extinguish the fire with the help of various mechanical installations during a fire (Aycı, 2021). Image 3.7 shows smoke detector.

Image 3.7. Smoke detector (URL-15)

3.4. Human Behavior during the Evacuation Process in case of Fire

Fire response performance refers to an individual's ability to detect and assess danger signals, make effective decisions, and take appropriate actions to survive a fire with minimal or no health impacts (Kobes et al., 2008).

The level of fire response performance in the event of a structure fire is identified by three elements. According to Kobes et al. (2010), these are the features of buildings, people, and fire.

These essential factors are illustrated by characteristic in Figure 3.11 The primary element directly affecting fire response performance is the fire's nature—it involves the ignition and combustion of materials, producing both heat and smoke. Additionally, building features significantly influence this performance, as structures are enclosed environments where people engage in various activities.

Finally, human nature also has a direct and major influence on the degree of fire response performance, and to analyse this, behaviour is examined both in terms of individuals (personal characteristics) and groups of people (social and situational characteristics).

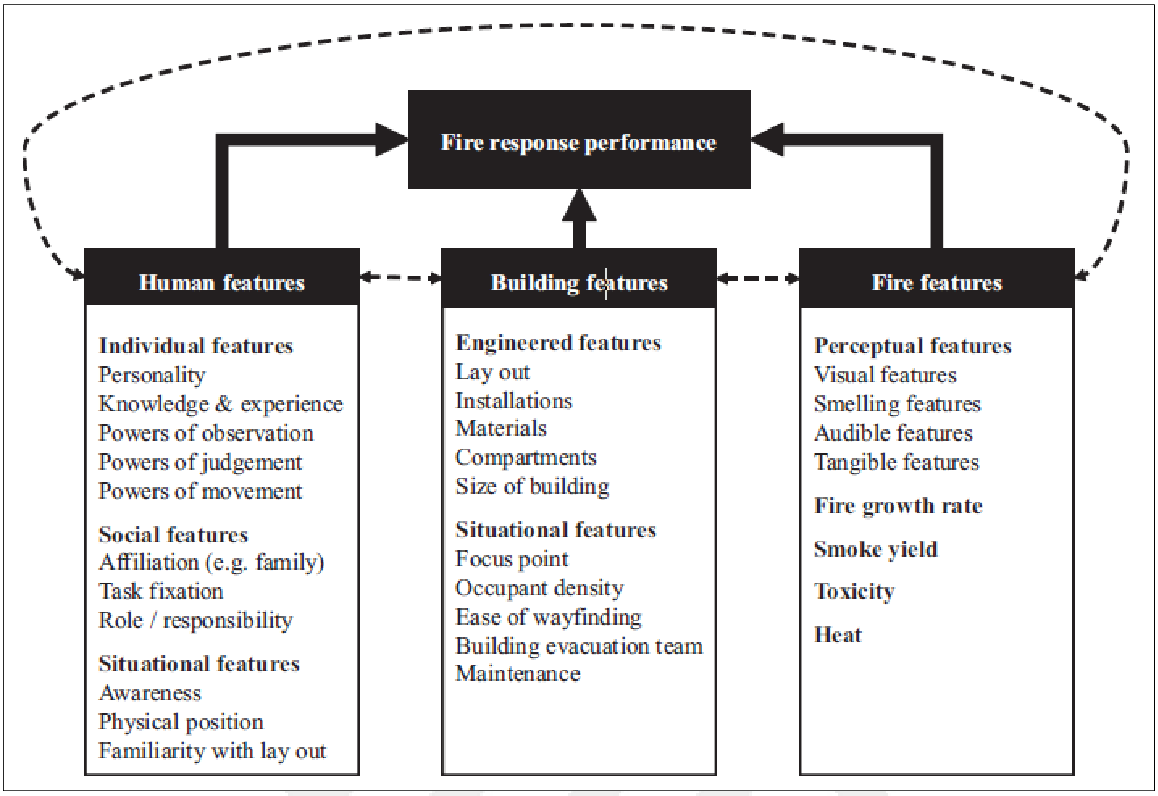


Figure 3.12. Fire response performance model (Kobes et al., 2010)

This chapter's goal is to give readers a fundamental understanding of fire theory and human behavior. The way individuals react to fire and similar situations within buildings, infrastructure, or transport systems is influenced by factors such as their awareness levels, belief systems, alertness, motivations, agreements, attitudes, and coping strategies.

The highly interdisciplinary study of human behavior under fire involves practitioners from a wide range of fields, including engineering and computer science to social sciences such as sociology and psychology, as well as areas focused on human interaction and system design, including human factors, communication, ergonomics (Kuligowski, 2016). Reducing the risk of fire for humans is the main goal of human behavior investigation and its practical application. Human fire response theory can be developed by creating and gathering both quantitative and qualitative data on human reactions. Advancing current fire safety engineering designs, performance-based regulations, evacuation modeling, and fire safety management requires a comprehensive understanding of human behavior during emergencies (Kuligowski, 2016).

The pre-evacuation and movement periods are two basic categories that are frequently used to clumsily describe how people react to fires. The pre-evacuation period calculates the interval between the start of ignition and the moment when a person or group starts moving purposefully to a safe location. The evacuation or movement phase is then defined as the time frame during which a purposeful relocation to safety takes place (Kuligowski, 2016).

The pre-evacuation and movement stages include several sub-phases that engineers need to understand, as depicted in Figure 3.12. For instance, there may be at least three subphases during the pre-evacuation period (Kuligowski, 2016):

• The pre-alarm phase refers to the interval between the fire's ignition and the activation of the building's alarm system or when occupants become aware of the fire through cues such as visible smoke or information from staff.
• The decision-making stage of evacuation occurs when occupants receive or actively seek information about the fire and others' reactions, which they then evaluate to decide if protective actions, like evacuation, are necessary.
• The protective action phase, during which people take specific steps to safeguard themselves or others before starting an evacuation, such as gathering personal possessions or helping others get ready.

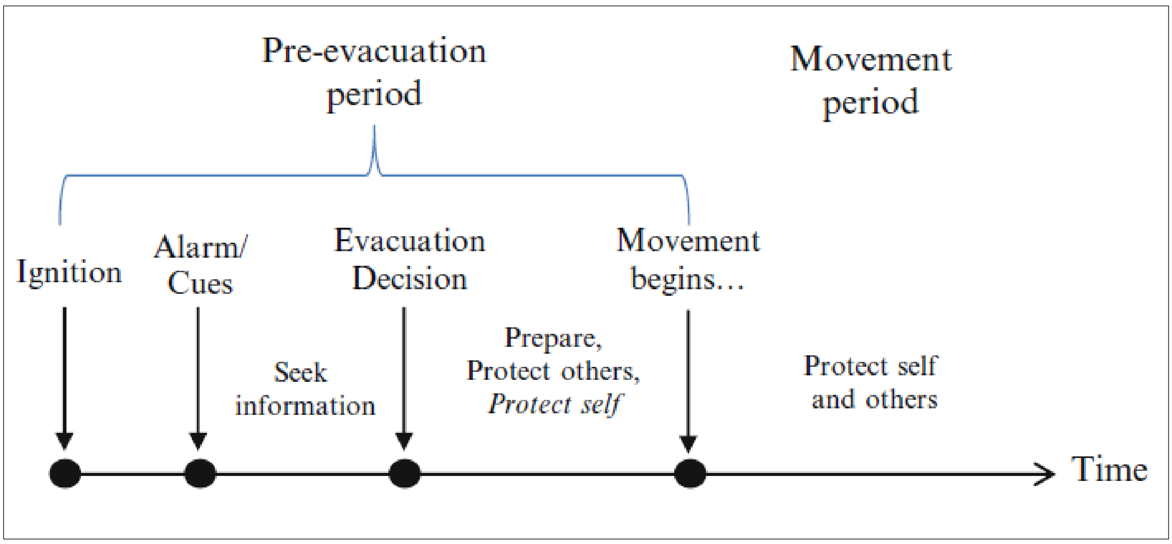


Figure 3.13. A human response timeline for a building fire emergency (Kuligowski, 2016)

Understanding these stages is crucial because, in some building types or situations involving building emergencies, the pre-evacuation phase may be much longer than the moving period during an evacuation.

<u>Panic behavior</u>

The majority of definitions define panic as a behavioral reaction that includes lavish and careless effort and involves flight or escaping. Panic is not always confined to a single person; it can be imitated and embraced by a group of people (collective flight or mass panic) (Kuligowski, 2016). People who are in a panic respond erratically, which hinders the evacuation procedure.

<u>Disaster shock</u>

Fear frequently immobilizes people who do not act unreasonably (i.e., panic) during emergencies.

The following three findings about disaster shock were discovered by disaster research carried out between 1943 and 1983 (Kuligowski, 2016; Fritz, 1954):
(1) Sudden onset disaster occurrences with no warning and widespread physical and social devastation are more likely to cause disaster shock;

(2) A small number of the population is impacted by disaster shock in any given incident;
(3) disaster shock often happens in the hours or days immediately following a tragedy.

<u>Group mind</u>

The idea that when a calamity strikes, people join a group and the group responds to the situation is known as group consciousness.

It is more likely that groups are made up of a diverse range of people, as has been observed in real crisis situations. Groups are more prone to practice what is known as "a division of labor" during disasters, whereby specific members of the group assume specific responsibilities depending on their backgrounds and/or connections with other members of the group. These roles complement one another and enable the group to function. Therefore, to fully comprehend human behavior in fire, it is crucial to comprehend the division of labor inside the groupings as well as the traits, backgrounds, choices, and behaviors of the members within the group (Kuligowski, 2016).

3.5. The Fire Evacuation Process

Since industrial buildings are crowded architectural structures in terms of user load, it is very important to analyze the evacuation process correctly. To provide life safety in case of fire, it is necessary to consider that human behavior and the evacuation process are two complementary concepts. An essential component of the emergency response plan for handling and controlling different crises or disasters is the evacuation procedure (Özdamar, 2020).

An essential temporal concept in the evacuation process is evacuation time, which measures how long it takes for residents to leave the hazardous area and enter a safe area after realizing there is a threat and beginning to evacuate. The life safety of a building can be ascertained by calculating the margin of safety, which is the difference between the calculated value of the needed evacuation time and the available time for people to exit the building, i.e. needed Safe Egress Time (RSET) and Available Safe Egress Time (ASET). Total Evacuation Time (TET), or the actual evacuation time needed for every occupant to leave the building safely and arrive at a safe location, was of the greatest significance (Ng, C. M., Chow, W. K., 2006).

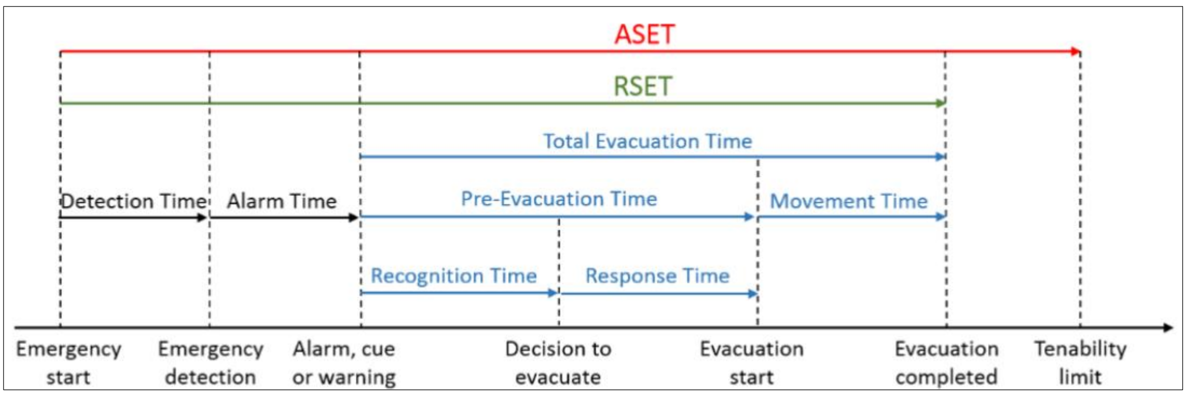


Figure 3.14. Evacuation timeline (Ruggiero, L., 2018)

Evacuation process divide into pre-evacuation time and evacuation time. The time between the alert and the initial movement to leave the building is known as the pre-evacuation time (Ng, C. M., Chow, W. K., 2006). Given that it may take longer than the evacuation (movement) time, pre-evacuation time can have a significant impact on the evacuation timeline, particularly for low-density buildings (Ng, C. M., , Chow, W. K., 2006). This is because residents of these kinds of buildings could find it more difficult to get in touch with other residents who are unaware of the problem. McConnell et al. examined the effects of the 9/11 incident on recognition time and response time, two stages of pre-evacuation time (McConnell, 2010). Pre-movement time is the most unexpected stage of the evacuation process since it is linked to human behavior, which is covered in the following section (Lovreglio, 2019). Lovreglio et al. created a database with nine fire incidents and 103 drills because pre-evacuation time is difficult to determine (Lovreglio, 2019). As a result, the database can be used as an input for evacuation simulations.

The movement phase, also known as the evacuation phase, is the period of time between the first evacuation movement and the final person to reach the exit (Proulx, 1995). Because it requires occupant movement, this phase has a greater physical aspect. Since the essential components related to movement time are calculable, engineers focused their research on them. According to Huo (2016), various factors influence evacuation movement time, including staircase features such as bottlenecks, occupants' physical characteristics, fatigue, group behavior, merging dynamics, opposing flows (counterflow), and crowd congestion.

The two primary definitions used to assess a building's safe egress are RSET and ASET. ASET is the amount of time that passes between an ignition and the development of circumstances that the human body cannot withstand (Wang, 2015). According to Sujatmiko (2014), RSET is the amount of time needed for every resident to arrive at the safe area. According to Sujatmiko (2014), RSET consists of four phases: detection, notification, pre-evacuation, and evacuation. Because RSET is shorter than ASET, it is a crucial checkpoint to prevent injuries to people during the evacuation procedure. Figure 3.14 illustrates the evacuation timeline, which is a complicated series of actions that begin with ignition. Before unsustainable conditions (visibility, temperature, and toxicity) arise, the rescue or evacuation must be terminated (Satır and Topraklı, 2020).

4. NATIONAL AND INTERNATIONAL FIRE LEGISLATION IN THE SCOPE OF PASSIVE PROTECTION IN INDUSTRIAL BUILDINGS

National and international regulations fulfill an important function by acting as a guide for architects and engineers in the implementation of passive and active fire safety measures. The duty of protecting civilians against fire has been taken up by the governments of all industrialized nations. Legislation makes the required legislation for this.

Currently, countries have their own regulations in place to ensure fire safety within their borders. The provisions of these regulations vary depending on when they were introduced and the level of development of the country. While some provisions within the regulations are restrictive, others offer designers a wide range of possibilities. Within the scope of the regulations, there are fire safety measures that must be taken in industrial buildings. These fire safety measures represent the minimum requirements. Considering that fires can cause significant loss of life and property, it is important to implement regulations and adopt safer designs, select appropriate materials, and propose systems to ensure safety. In this section of the thesis, fire safety in industrial buildings has been addressed in national legislation, within the framework of TRRFP, in US legislation, within the framework of NFPA 101 Life Safety Code, in European legislation, and within the framework of British regulations (BR).

4.1. Investigation of National Fire Legislation in Industrial Buildings

Enforced in 2007, Turkey's Regulation on Fire Protection (TRRFP) forms a fundamental aspect of the nation's structural fire safety framework (TRRFP, 2007). It establishes fire-specific safety standards to safeguard buildings and has undergone multiple revisions since its inception.

While the regulation predominantly applies to standard building types, specialized environments such as subways, marinas, helipads, tunnels, stadiums, and airports are subject to distinct provisions. In cases where the TRRFP lacks sufficient guidance for these unique settings, supplementary fire safety rules and alternative standards may be adopted to ensure adequate protection. In this context, in designing the TRRFP as a regulation, the prescriptive-based regulation has to a certain extent limited the use and dissemination of performance-based approaches (Yaman and Kurtay, 2021).

Although the regulation promotes adherence to established standards, it simultaneously restricts flexibility, potentially hindering the broader assessment and adaptation of fire safety practices. While the TRRFP outlines fire safety requirements for assembly buildings, it lacks provisions for performance-based approaches and evacuation modeling. This highlights a critical gap, emphasizing the necessity of incorporating evacuation simulations and time-based analyses aligned with the applied methodologies of fire safety–advanced countries such as the United States (Yaman, 2025).

Turkey's regulation on fire protection (TRRFP)

Classification of industrial occupancy

According to TRRFP Article 14, industrial structures encompass buildings and facilities designated for the production of various goods, as well as for operations such as processing, assembling, mixing, cleaning, washing, packaging, storage, distribution, and maintenance. This classification includes a broad spectrum of facilities, including factories, sawmills, laundries, textile manufacturing plants, energy generation sites, food processing units, filling and discharging stations, dry cleaning centers, mining and refining facilities, and other comparable establishments (Council of Ministers, 2007).

Building hazard classification

According to TRRFP Article 19, the hazard class of a building or a section thereof is determined based on the characteristics of the building and the nature of the operations and activities carried out in the building. When designing fire extinguishing systems and compartments in a building or a section thereof, the following hazard classification is taken into account during the design process (Council of Ministers, 2007):

Low-hazard areas: Areas containing materials with low fire load and combustibility, capable of withstanding fire for at least 30 minutes, and where no single compartment area exceeds 126 m^2.

Moderate-hazard areas: Areas containing combustible materials with moderate fire load and flammability (Table 4.1).

High-hazard areas: Areas containing materials with high fire load and flammability that can cause a fire to spread and grow rapidly.

Table 4.1. TRRFP Annex 1/B Table of medium-risk areas (Council of Ministers, 2007)

Type of use	Moderate Hazard-3
Paper	Binderies, cardboard mills, paper mills, printing and printing presses

Occupant load factor

According to TRRFP Annex 5/A Occupant load factor table (Table 4.2), the user load for factory production areas is 10 m2/person. Occupant load factor for areas that may be found in industrial buildings are listed below (Council of Ministers, 2007).

Table 4.2. TRRFP Annex 5/A Occupant load factor table (Council of Ministers, 2007)

Areas of use	m2/person
Factory production areas, packaging areas	10
Multipurpose halls (ballrooms, etc.), restaurants, cafeterias, waiting rooms,	1.5
Reception areas, waiting areas, atrium floors	3
Fitness centers	5
Offices	10
Bedrooms	10
Kitchens, laundry rooms	10
Storage rooms, machine rooms	30

Maximum travel distance to exits

According to TRRFP Annex 5/B Longest escape distances and unit widths leading to exits (Table 4.3), for industrial buildings according to building use classes; maximum distance in one direction (m); if there is no sprinkler system; 15, if there is, 25; maximum distance in two directions (m); if there is no sprinkler system; 30, if there is, 60 m (Council of Ministers, 2007)

Table 4.3. TRRFP Annex 5/B Longest escape distances and unit widths leading to exits (Council of Ministers, 2007)

Class of Use	One direction maximum distance (m)		Two directions maximum distance (m)	
	No sprinkler system	With sprinkler system	No sprinkler system	With sprinkler system
Structures for Industrial Purposes	15	25	30	60

According to TRRFP Annex 5/B Longest escape distances and unit widths leading to exits (Table 4.4), the maximum distance for dead-end corridors (m); if there is no sprinkler system in the corridors, it should be 15 m, and if there is, it should be 20 m (Council of Ministers, 2007).

According to TRRFP Annex 5/B Longest escape distances and unit widths leading to exits (Table 4.4), the number of people per unit width; at door openings; the exit door should be 100, other doors and corridor doors 80, escape staircases 60, ramps and corridors 100 (Council of Ministers, 2007).

Table 4.4. TRRFP Annex 5/B Longest escape distances and unit widths leading to exits (Council of Ministers, 2007)

Class of Use	Number of people per unit width				Dead-end corridor maximum distance(m)	
	Door Openings		Escape Stairs	Ramps and Corridors	Corridors	
	Exit door	Other doors and corridor doors			No sprinkler system	Sprinkler System
Structures for Industrial	100	80	60	100	15	20

Compartment areas

According to TRRFP Annex 4 Maximum compartment areas in buildings (Table 4.5), for industrial buildings classified by building use categories; for buildings classified as Medium Hazard-3 and above, the maximum compartment area should be 6,000 m², while for buildings classified as Medium Hazard-1 and Medium Hazard-2, it should be 15,000 m². Additionally, if appropriate fire control systems (such as automatic detection, sprinkler systems, and smoke exhaust systems) are installed in the buildings, the compartment area can be doubled (Council of Ministers, 2007)

Table 4.5. TRRFP Annex-4 Maximum compartment areas in buildings (Council of Ministers, 2007)

Classes of building use		Maximum compartment area (m2)
Industrial Structures	Medium Hazard-3 and above (See Annex 1)	6000 (1)
	Medium Hazard-1 and Medium Hazard-2 (See Annex 1)	15000
Note :(1) If appropriate fire control systems (automatic detection, sprinkler system and smoke evacuation system etc.) are installed in the buildings, the compartment area can be doubled.		

Minimum periods of fire resistance

According to TRRFP Annex 3/C Fire resistance periods according to building use classes (Table 4.6); If there is a sprinkler system for industrial buildings, the basement depth is 90 minutes if it is more than 10 m and 60 minutes if it is less than 10 m. For entrance or upper floors, if the building height is less than 5 m, the fire resistance time is 30 minutes; if less than 21.50 m, it is 60 minutes; if less than 30.50 m, it is 90 minutes; and if more than 30.5 m, it is 120 minutes. If there is no sprinkler system, the basement depth is 120 minutes if it is more than 10 meters, and 90 minutes if it is less than 10 meters. If the building height is less than 5 m on the ground or upper floors, the fire resistance rating is 60 minutes; if less than 21.50 m, it is 90 minutes; if less than 30.50 m, it is 90 minutes; and if more than 30.5 m, it is not permitted (Council of Ministers, 2007)

Table 4.6. TRRFP Annex-3/C Fire resistance periods according to building use classes (Council of Ministers, 2007)

Building Use Classes	Fire Resistance Times of Building Elements (min)					
	Basement Floors(1) (including the slab on top)		Entrance or Upper Floors			
	Depth of Basement Floor(s)*(m)		Building Height (m)			
	More than 10 m	Less than 10 m	Less than 5 m	Less than 21.50 m	Less than 30.50 m	More than 30.50 m
Industrial Buildings - no sprinkler system	120	90	60	90	120	Not allowed
- sprinkler system	90	60	30[2]	60	90	120[3]

(1) The floor above a basement (or, if there is more than one basement, the floor above the uppermost basement) shall meet the provisions if the fire resistance times for the ground and upper floors are higher.
(2) Increased to at least 60 minutes for fire compartment walls separating buildings
(3) It may be reduced to 90 minutes for elements that do not form part of the load-bearing system.

Buildings requiring automatic detection systems

According to TRRFP Annex 7 Buildings requiring automatic detection systems (Table 4.7), an automatic detection system is required for industrial buildings with a height greater than 21.50 m and a total enclosed area greater than 7,500 m2, depending on the building usage class (Council of Ministers, 2007)

Table 4.7. TRRFP Annex 7 Buildings requiring automatic detection systems (Council of Ministers, 2007)

	Building Height (m)	Total closed area of the building (m^2)
Structures for Industrial Purposes	>21,50	>7500

4.2. Investigation of International Fire Legislation in Industrial Buildings

There are regulations in the form of Building Regulations for flexible designs in England and Wales. It has parallel components in that it is the regulation from which our regulations are inspired. In the UK, building regulations are legislative instruments or regulations designed to make sure that the policies outlined in the applicable laws are followed. In the UK, the majority of construction projects require approval from building rules. The Building Regulations in England and Wales are organized under 18 distinct categories, each identified by a specific letter. These categories address various aspects of construction, including workmanship, appropriate material usage, structural integrity, weather resistance, fire safety and evacuation routes, acoustic insulation, ventilation, access to potable water, fall prevention, sanitation, accessibility for individuals with disabilities, electrical safety, drainage, building security, and provisions for high-speed broadband infrastructure.

The United States fire regulations include codes from the National Fire Protection Association (NFPA). The codes within the NFPA 101 Life Safety Code are primarily based on the IBC and have undergone many changes to date (White, N., Delichatsios, M., 2014).

In the US, the federal government does not impose any sanctions on states regarding the creation of building or construction regulations. The task of creating regulations is carried out by private institutions such as the International Code Council (ICC) and the National Fire Protection Association (NFPA). These regulations (codes) are then presented to the public for acceptance by states and local governments. Building design and fire system codes are traditionally prepared based on regulations.

In this thesis, NFPA 101 Life Safety Code was selected to analyze the legislation related to passive fire safety in industrial buildings in the United States. The purpose of the NFPA 101 Life Safety Code is to ensure that buildings and structures provide minimum requirements for functionally appropriate design, operation, and maintenance to ensure life safety in the event of a fire (NFPA, 2018).

The Building Regulations 2010 (BR)

Classification of industrial occupancy

Factories and related premises are those used for:
• the manufacturing, modification, repair, or processing of any item, cleaning, washing, disassembling, or adapting materials or products
• generating energy or electrical power
• the slaughtering and processing of livestock

are defined as industrial buildings according to BR Table 0.1 Classification of purpose groups (Hm Government, 2021).

Occupant load factor

The general industrial occupancy must ensure a means of egress for minumum 2000 persons, rest on an occupant load factor of 100 ft2 (9.3 m2) per person (Hm Government, 2021).

Maximum travel distance to exits

According to BR Table 2.1 Limitations on travel distance (Table 4.8), for industrial buildings according to purpose group; limitations on travel distance in one direction (m); if there is normal hazard; 12 m, if there is higher hazard, 25 m; more than one direction (m); if there is normal hazard; 25 m, if there is higher hazard, 45 m (Hm Government, 2021).

Table 4.8. BR Table 2.1 Limitations on travel distance (Hm Government, 2021)

Purpose group	Maximum travel distance where travel is possible in:		
		One direction only (m)	More than one direction (m)
Industrial	Normal hazard	12	25
	Higher hazard	25	45

Compartment areas

According to BR Table 8.1 Maximum dimensions of building or compartment for industrial buildings (Table 4.9); Without sprinkler system; for single storey buildings, height of floor of top storey above ground level (m), if it is not more than 18 m, no limit; if it is more than 18 m, not applicable. For multi-storey buildings; height of floor of top storey above ground level (m), if it is not more than 18 m: compartment area should be 7000 m2; if it is more than 18 m, compartment area should be 2000 m2 (Hm Government, 2021).

With sprinkler system, for single storey buildings, height of floor of top storey above ground level (m), if it is not more than 18 m, no limit; if it is more than 18 m, not applicable. For multi-storey buildings, height of floor of top storey above ground level (m), if it is not more than 18 m: compartment area should be 14000 m2; if it is more than 18 m: compartment area should be 4000 m^2 (Hm Government, 2021).

Table 4.9. BR Table 8.1 Maximum dimensions of building or compartment (Hm Government, 2021)

Purpose group of building		Height of floor of top storey above ground level (m)	Maximum floor area of any one storey in the building or any one storey in a compartment (m2)	
			Single storey buildings	Multi-storey buildings
Industrial	Without sprinkler system	Not more than 18	No limit	7000
		More than 18	N/A	2000
	With sprinkler system	Not more than 18	No limit	14000
		More than 18	N/A	4000
N/A : Not applicable				

Minimum periods of fire resistance

According to BR Table.B4 Minimum periods of fire resistance for industrial buildings (Table 4.10); without sprinkler system; for basement storey including floor over, depth (m) of the lowest basement, if it is more than 10 m, fire resistance should be 120 min, if it is up to 10 m, fire resistance should be 60 min; for ground or upper storey, height (m) of top floor above ground, in a building, if it is up to 5 m, fire resistance should be 60 min; if it is up to 11 m, fire resistance should be 60 min; if it is up to 18 m, fire resistance should be 60 min; if it is up to 30 m, fire resistance should be 90 min; if it is more than 30 m, fire resistance should not permitted (Hm Government, 2021).

With sprinkler system; for basement storey including floor over, depth (m) of the lowest basement, if it is more than 10 m, fire resistance should be 60 min, if it is up to 10 m, fire resistance should be 60 min; for ground or upper storey, height (m) of top floor above ground, in a building, if it is up to 5 m, fire resistance should be 30 min; if it is up to 11 m, fire resistance should be 60 min; if it is up to 18 m, fire resistance should be 60 min; if it is up to 30 m, fire resistance should be 60 min; if it is more than 30 m, fire resistance should be 120 min (Hm Government, 2021).

Table 4.10. BR Table.B4 Minimum periods of fire resistance (Hm Government, 2021)

Purpose group of building		Basement storey including floor over		Ground or upper storey				
		Depth (m) of the lowest basement		Height (m) of top floor above ground, in a building				
		More than 10	Up to 10	Up to 5	Up to 15	Up to 18	Up to 30	More than 30
Industrial	Without sprinkler system	120 min	90 min	60 min	90 min	90 min	120 min	Not permitted
	With sprinkler system	90 min	60 min	30 min	60 min	60 min	90 min	120 min

<u>NFPA 101 life safety code</u>

Classification of industrial occupancy

According to NFPA 101 Life Safety Code (2018), industrial occupancy refers to any facility where goods are produced or where activities such as processing, assembling, mixing, packaging, finishing, decorating, or repairing are carried out. As outlined in NFPA 101 Life Safety Code, industrial occupancies encompass the following categories:

(1) Drycleaning plants
(2) Factories of all kinds

(3) Food processing plants

(4) Gas plants

(5) Hangars (for servicing/maintenance)

(6) Laundries

(7) Power plants

(8) Pumping stations

(9) Refineries

(10) Sawmills

(11) Telephone exchanges

Occupant load factor

According to NFPA 101 Life Safety Code Table 7.3.1.2 (Table 4.11), while occupant load factor for general and high hazard industrial occupancies is 9.3 m2/person, for special-purpose industrial occupancies is not applicable (NFPA, 2018).

Table 4.11. NFPA 101 Life Safety Code Table 7.3.1.2 Occupant load factor (NFPA 101, 2018)

Areas of use		ft2/person	m2/person
Industrial Use	General and high hazard industrial	100	9.3
	Special-purpose industrial	NA	NA

Maximum travel distance to exits

According to NFPA 101 Life Safety Code Table 40.2.6.1 (Table 4.12); for general industrial occupancy; if it is protected by sprinkler system, maximum travel distance to exits should be 76 m; if it is not protected by sprinkler system, maximum travel distance to exits should be 61 m. For special-purpose industrial occupancy, if it is protected by sprinkler system, maximum travel distance to exits should be 122 m; if it is not protected by sprinkler system, maximum travel distance to exits should be 91 m. For high hazard industrial occupancy, if it is protected by sprinkler system, maximum travel distance to exits should be 23 m; if it is not protected by sprinkler system, maximum travel distance to exits should not permitted (NFPA, 2018).

Table 4.12. NFPA 101 Life Safety Code Table 40.2.6.1 Maximum travel distance to exits (NFPA, 2018)

Level of Protection	General Industrial Occupancy		Special-Purpose Industrial Occupancy		High Hazard Industrial Occupancy	
	ft	m	ft	m	ft	m
Protected by Sprinkler system	250	76	400	122	75	23
Not protected by sprinkler system	200	61	300	91	NP	NP
NP: Not permitted						

According to NFPA 101 Life Safety Code Table 40.2.5.1 Arrangement of means of egress (Table 4.13); for general industrial occupancy and special-purpose industrial occupancy, whether there is a spring or not; if there is dead-end corridor, distance of means of egress should be 15 m. For common path of corridor; if there is protected by sprinkler system, distance of means of egress should be 30 m; if there is not protected by sprinkler system, distance of means of egress should be 15 m (NFPA, 2018).

Table 4.13. NFPA 101 Life Safety Code Table 40.2.5.1 Arrangement of means of egress (NFPA, 2018)

Level of Protection		General Industrial Occupancy		Special-Purpose Industrial Occupancy		High Hazard Industrial Occupancy
		ft	m	ft	m	
Dead-End Corridor	Protected by Sprinkler system	50	15	50	15	Prohibited
	Not protected by sprinkler system	50	15	50	15	Prohibited
Common Path of Travel	Protected by sprinkler system	100	30	100	30	Prohibited
	Not protected by sprinkler system	50	15	50	15	Prohibited

Minimum periods of fire resistance

According to NFPA 101 Life Safety Code article 40.3.6 Corridors; all newly constructed corridors in industrial occupancies that serve over 30 individuals must possess a minimum fire resistance rating of one hour, and any openings within these corridors must be protected with door assemblies rated for at least 20 minutes of fire resistance (NFPA, 2018).

Image 4.1 shows means of escape signage. Table 4.14 shows the summary of the comparison of regulations in the scope of industrial buildings.

Image 4.1. Means of escape signage (URL-16)

Table 4.14. The summary of the comparison of regulations in the scope of industrial buildings

SUBJECT TITLE	TRFP (For use in Turkey)	The Building Regulations,2010 (For use in England)	NFPA 101 (For use in America)
Classification of Industrial Occupancy	Article 14- (1) Industrial buildings are factories and buildings and structures for processing, assembly, mixing, cleaning, washing, packaging, storage, distribution and repair of all kinds of products. All kinds of factories, sawmills, laundries, textile production facilities, energy production facilities, food processing facilities, filling and unloading facilities, dry cleaning facilities, mineral processing facilities, refineries and similar places are included in this class.	Table 0.1 Classification of purpose groups Factories and other premises used for any of the following: •manufacturing, altering, repairing, cleaning, washing, breaking up, adapting or processing any article • generating power • slaughtering livestock.	40.1.1.4 Industrial occupancies shall include factories making products of all kinds and properties used for operations such as processing, assembling, mixing, packaging, finishing or decorating, repairing, and similar operations.

Table 4.14. (Continued) The summary of the comparison of regulations in the scope of industrial buildings

SUBJECT TITLE	TRFP (For use in Turkey)	The Building Regulations,2010 (For use in England)	NFPA 101 (For use in America)
Occupant Load Factor	Annex- 5/A Occupant Load Factor 10 m2/person	40.1.7* Occupant Load The general industrial occupancy must provide a means of egress for at least 2000 persons, based on an occupant load factor of 100 ft2 (9.3 m2) per person.	Table 7.3.1.2 Occupant Load Factor General and high hazard industrial; 9.3 m2/person
Maximum Travel Distance to Exits	Annex-5B Longest Escape Distances to Exits Maximum distance in one direction (m); 15 if there is no sprinkler system; 25 if there is, Maximum distance (m) in two directions; if there is no sprinkler system; 30 if there is, 60 m. Maximum distance to dead-end corridor(m) Corridors; if there is no sprinkler system; 15 if there is; 20 if there is	Table 2.1 Limitations on travel distance Normal hazard; One direction only (m), 25 More than one direction (m), 45 Higher hazard; One direction only (m), 12 More than one direction (m), 25	Table 40.2.6.1 Maximum travel distance to exits For General Industrial Occupancy Protected; 76 m Not protected ;61 m Dead-End Corridor Protected throughout by an approved, supervised automatic sprinkler system; 15 m Not protected ;15 m Common Path of Travel Protected; 30 m Not protected ;15 m

Table 4.14. (Continued) The summary of the comparison of regulations in the scope of industrial buildings

SUBJECT TITLE	TRFP (For use in Turkey)	The Building Regulations,2010 (For use in England)	NFPA 101 (For use in America)
Compartment Areas	Annex-4 Maximum Compartment Areas in Buildings Medium Hazard-3 and above, 6000 m2 Medium Hazard-1 and Medium Hazard-2 are 15000 m2	Table 8.1 Maximum dimensions of building or compartment Without sprinkler system; Single storey buildings Height of floor of top storey above ground level (m), Not more than 18: No limit; More than 18: N/A. Multi-storey buildings Height of floor of top storey above ground level (m), Not more than 18: 7000; More than 18: 2000. With sprinkler system, Single storey buildings Height of floor of top storey above ground level (m), Not more than 18: No limit; More than 18: N/A. Multi-storey buildings Height of floor of top storey above ground level (m), Not more than 18: 14000; More than 18: 4000.	No specific article on this issue has been found.

Table 4.14. (Continued) The summary of the comparison of regulations in the scope of industrial buildings

SUBJECT TITLE	TRFP (For use in Turkey)	The Building Regulations,2010 (For use in England)	NFPA 101 (For use in America)
Minimum Periods of Fire Resistance	Annex-3/C Fire Resistance Periods According to Building Use Classes - Less than 5 m, if there is no sprinkler system; 60 if there is 30 -Less than 21.50 m, if there is no sprinkler system; 90 if there is, 60 -Less than 30.50 m; if there is no sprinkler system 120 if there is, 90 minute building elements should have fire resistance periods.	Table B4 Minimum periods of fire resistance Without sprinkler system, Up to 5, 60 min,; Up to 30, 120 min, With sprinkler system Up to 5, 30 min; Up to 30, 90 min	40.3.6 Corridors All new industrial occupancy corridors serving more than 30 persons would be required to have a 1-hour fire resistance rating, with openings protected by 20-minute fire protection–rated door assemblies.

5. A CASE STUDY: SIMULATION OF ESCAPE EVACUATION FROM AN INDUSTRIAL BUILDING

In this master's thesis examining fire safety in industrial buildings, the case study was modeled using the Pathfinder software and evaluated according to the Turkish Regulation (TRRFP) by analyzing the evacuation time of an printing building planned to be constructed in Ankara using a performance-based fire escape simulation program. Tools such as Thunderhead Pathfinder focus on pedestrian dynamics and congestion analysis to provide accurate measurements of evacuation times and identify potential bottlenecks (Godes et al., 2024). The primary objective in creating the model was to ensure that the building could be evacuated in a timeframe that would allow all users to safely exit the building. Analyses were conducted using the building modeled with the parameters provided in Section 5.1. Section 5.2 covers the analysis of simulation programs, while Section 5.4 covers the simulation of the case study. Section 5.4 discusses the findings and the results are presented in Section 5.5.

5.1. General Information about the Building

Location: Ankara
Use: Industrial Building
Bearing system: Reinforced concrete system and steel roof construction
Number of floors: 3 (Ground floor + First Floor + Technical Floor)
Building height: 15.00 m
Total Construction area: 6.414,38 m²

(a)

(b)

Image 5.1.a,b. 3D visuals of the printing service building

The case study is a printing service building planned to be constructed in Gölbaşı district of Ankara. The location of the building within the city is indicated in image 5.2. 3D visuals of the printing service building are shown in Image 5.1. Interdisciplinary project design studies have been completed, and the project has been approved. The design of the printing building is intended to be created in compliance with the TRRFP specifications. Passive safety measures of the case study were provided by utilizing regulations.

Image 5.2. Location of the printing service building within the city

TRRFP access routes to buildings according to article 22, “The horizontal distance from the furthest point accessible by fire engines to any point on the exterior of the building may not exceed 45 m.” According to this regulation, firefighting vehicles can easily access the project in case study. Figure 5.1 shows the firefighting access points and assembly points on the site plan.

Figure 5.1. Site plan of the printing service building

The project consists of 2 floors and a roof floor. These floors are ground floor, 1st floor and technical volume floor. The printing building is evaluated in the "industrial buildings" use class in accordance with Article 14 of the TRRFP. The building has a sprinkler system. There are four fire escapes and 2 elevators. When the alternatives for exits are checked, it is understood that direct exits and escape stairs are alternatives to each other on a floor basis. For example, as shown in Figure 5.2, the diagonal of the area is 103.8 m. When the distance between the escapes is obtained by calculating 1/3 of the diagonal, a value of 34.6 m is reached. That is, the minimum distance between escapes should not be less than 34.6 m. As a result, since the distance between the escapes in Figure 5.2 is 60.3 m, it can be concluded that the escapes are alternative to each other.

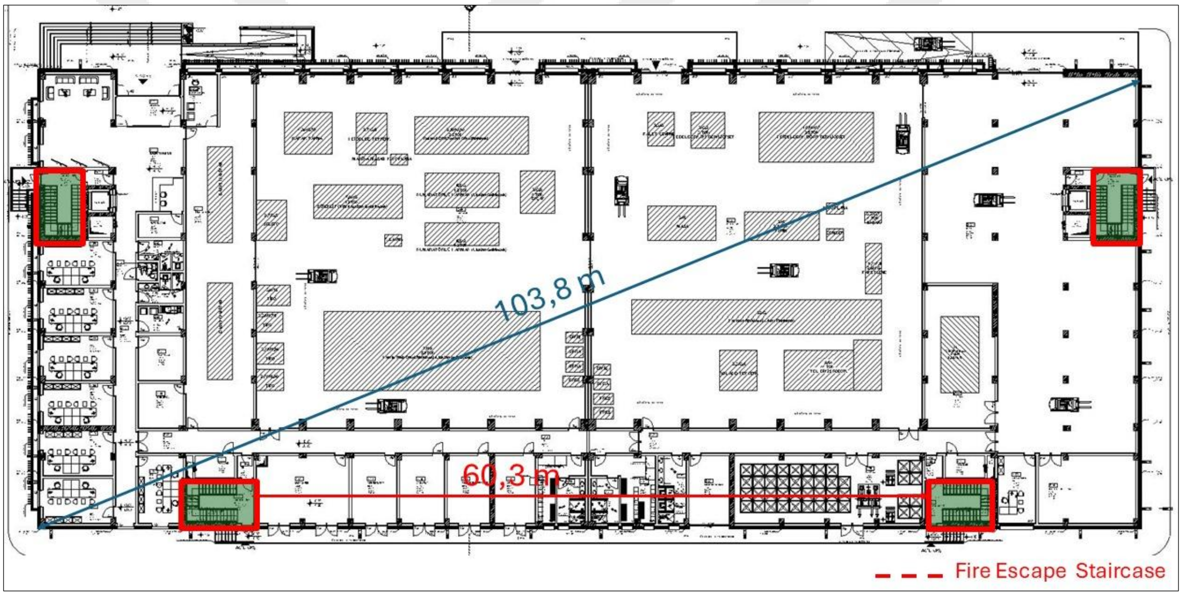


Figure 5.2. Alternativity in exits in the case study printing service building

Evacuation (escape) facilities, according to the definition made by NFPA 101 Life Safety Code, are the facilities that reach from any point of the building or structure to the public space with uninterrupted and unobstructed passages. It is divided into three stages: exits, access to exits and evacuation after exit. In the rest of the definition, it is emphasized that evacuation consists of vertical (stairs, elevators, ramps) and horizontal escape (horizontal exits, corridors, passages) (NFPA, 2018).

The floors are analyzed under four headings: general information, horizontal escape routes, vertical escape routes and evacuation strategy.

Ground floor

General information and class of use

It consists of 3.821 m² and is at ±0.00 level. The floor height is 5 m. As shown in Figure 5.3, the ground floor consists of a printing area, inkjet printer, 6 offices, waiting and exhibition area, paper trimming room, chemical storage, ctp room, printing area, staff room, tea room, reserve room, boiler room, compressor room, system room, main panel, water tank, storages and wc's. On the ground floor, there are production areas as well as technical rooms, offices and warehouses. Based on Article 31/5 of TRRFP, "In buildings where various sections or floors are designated for different functions or are used simultaneously for diverse purposes, egress requirements are either based on the most demanding use type throughout the entire building or floor, or they are individually assessed for each distinct section, depending on the context.", the main use class of the floor is evaluated in the "Industrial use" class (Council of Ministers of Turkey, 2015). Figure 5.3 shows the function diagram of the ground floor areas of the printing service building.

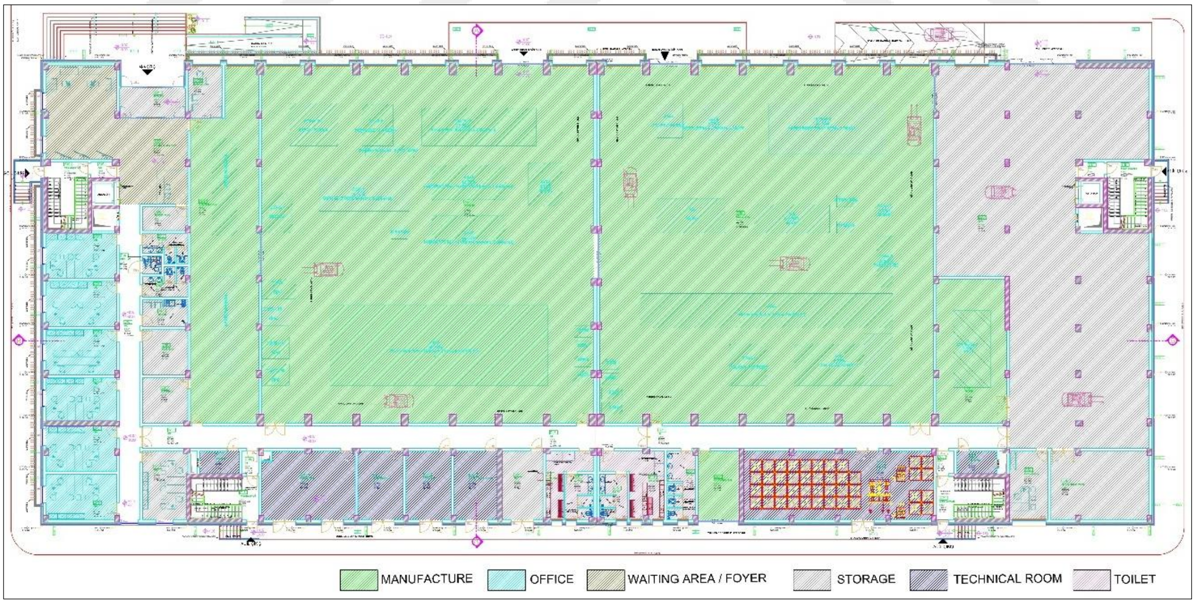


Figure 5.3. Function diagram of the ground floor areas of the printing service building

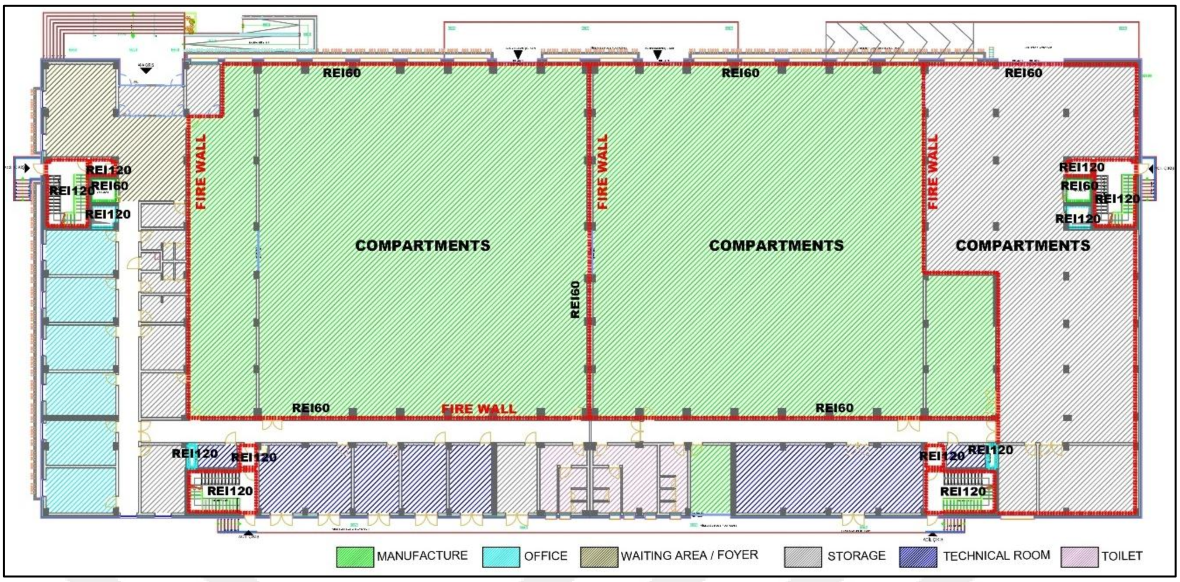


Figure 5.4. Fire compartmentation of printing service building

Figure 5.4 shows fire compartmentation demonstration of the case study. The walls marked in figure 5.4 are called "fire walls".

According to TRRFP Annex 4 Maximum compartment areas in buildings (Table 5.1), for industrial buildings classified by building use categories; for buildings classified as Medium Hazard-3 and above, the maximum compartment area should be 6,000 m². Additionally, if appropriate fire control systems (such as automatic detection, sprinkler systems, and smoke exhaust systems) are installed in the buildings, the compartment area can be doubled (Council of Ministers, 2007). In the case study, a 2,532 m² compartment was constructed, which falls under the medium hazard-3 class, thus complying with the regulation of a maximum compartment area of 6,000 m².

Table 5.1. TRRFP Annex-4 Maximum compartment areas in buildings (Council of Ministers, 2007)

Classes of building use		Maximum compartment area (m2)
Industrial Structures	Medium Hazard-3 and above (See Annex 1)	6000 (1)
	Medium Hazard-1 and Medium Hazard-2 (See Annex 1)	15000
Note :(1) If appropriate fire control systems (automatic detection, sprinkler system and smoke evacuation system etc.) are installed in the buildings, the compartment area can be doubled.		

Horizontal escape opportunities

As shown in Figure 5.5, there are fire safety halls and corridors on the ground floor, which form the escape route. Users pass through these escape routes and reach a safe point.

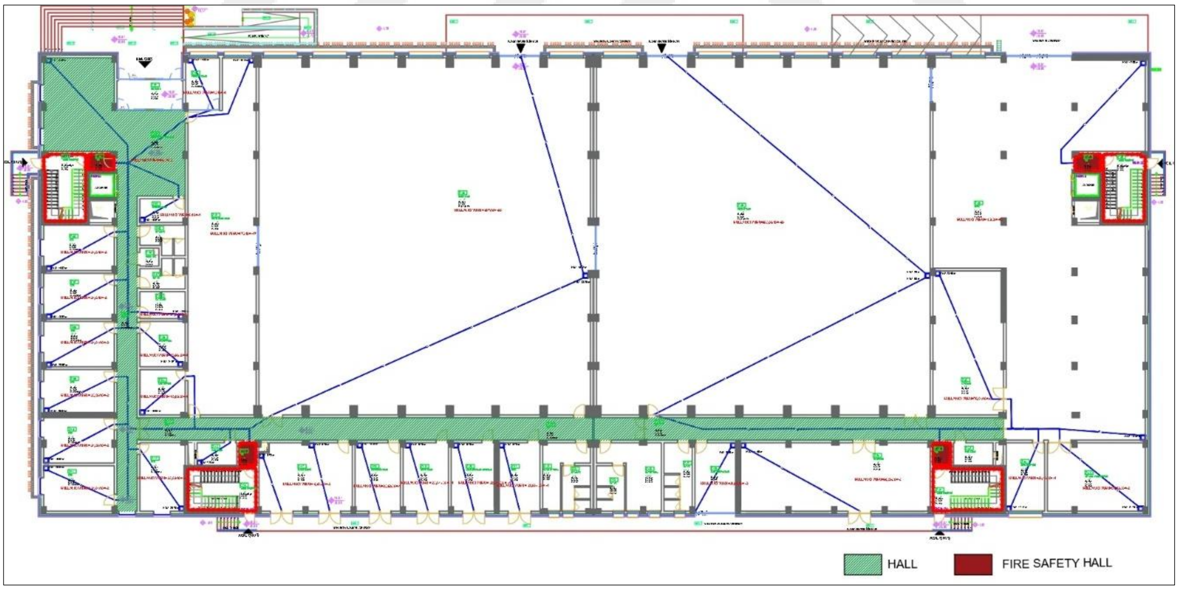


Figure 5.5. Printing service building ground floor horizontal escape ways

On the ground floor, the escape distance was measured up to the fire safety hall shown in Figure 5.5 the longest escape route is 53 m. In the TRRFP, there is a regulation shown in Table 5.2 that the two directions with the spring system should not exceed 60 m and the one direction should not exceed 25 m. Since the relevant project has a two direction and sprinkler system, the longest escape distances leading to the exits comply with the 60 m regulation. In this way, it is ensured that the users can reach the fire safety halls or directly to the outdoors within the appropriate distance and exit to a safe area.

Table 5.2. Longest escape distances to exits in industrial buildings (Council of Ministers, 2007)

Class of Use	One direction maximum distance (m)		Two directions maximum distance (m)	
	No sprinkler system	With sprinkler system	No sprinkler system	With sprinkler system
Industrial Buildings	15	25	30	60

Vertical escape opportunities

As shown in Figure 5.6, there are four fire escape stairs on the ground floor, which are vertical escape facilities. When the user load calculation is made in the areas where users can be found on the floor, the overall number of people on the floor is 287; Article 39/2 of the TRRFP states that "...there must be at least 2 exits in every place where 50 people exceed. If the number of people exceeds 500, there must be at least 3 exits and if the number of people exceeds 1000, there must be at least 4 exits." (Council of Ministers of Turkey, 2015). As seen in Figure 5.6, there are four fire escape stairs on the floor. All of the stairs are protected and each staircase opens to fire safety halls. The building has access to the outside through 4 fire escape stairs. There are also 4 exit doors to the outside, 1 of which is the main entrance. The building water base elevation is 1.05 m. There are 7 steps from the fire escape stairs to the outside.

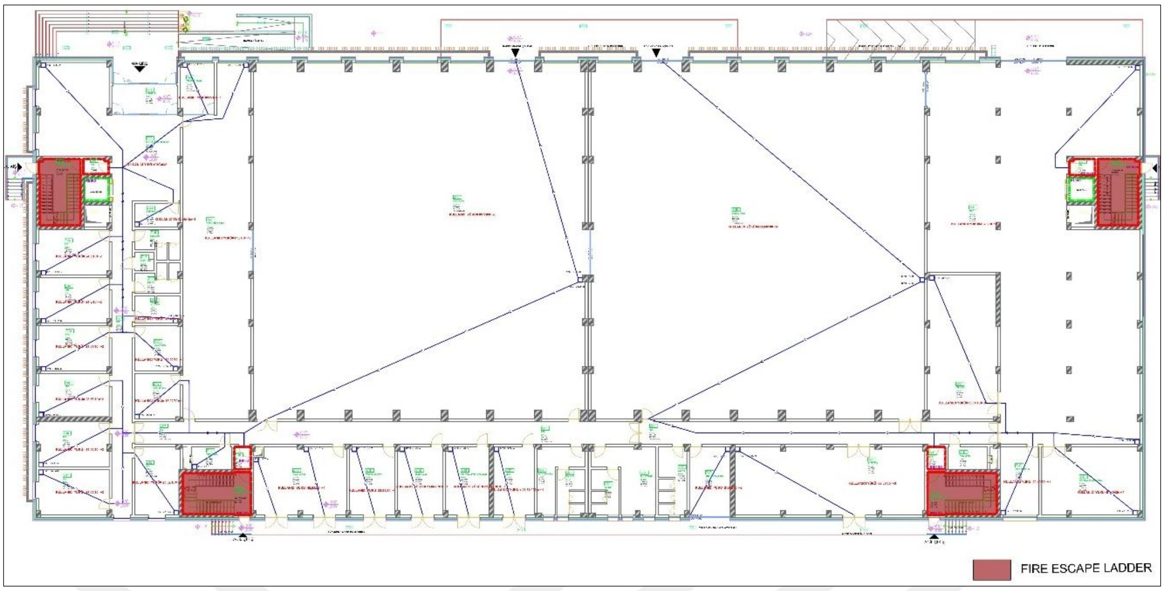


Figure 5.6. Printing service building ground floor vertical escape ways

Evacuation strategy

Occupants on the floor will use the four fire escape stairs; sufficient exit and escape width can be provided. There are also 4 exit doors to the outside, 1 of which is the main entrance. The escape routes of the case study printing service building are schematized in Figure 5.7; blue indicates exits, orange indicates exit access and green indicates post-exit evacuation.

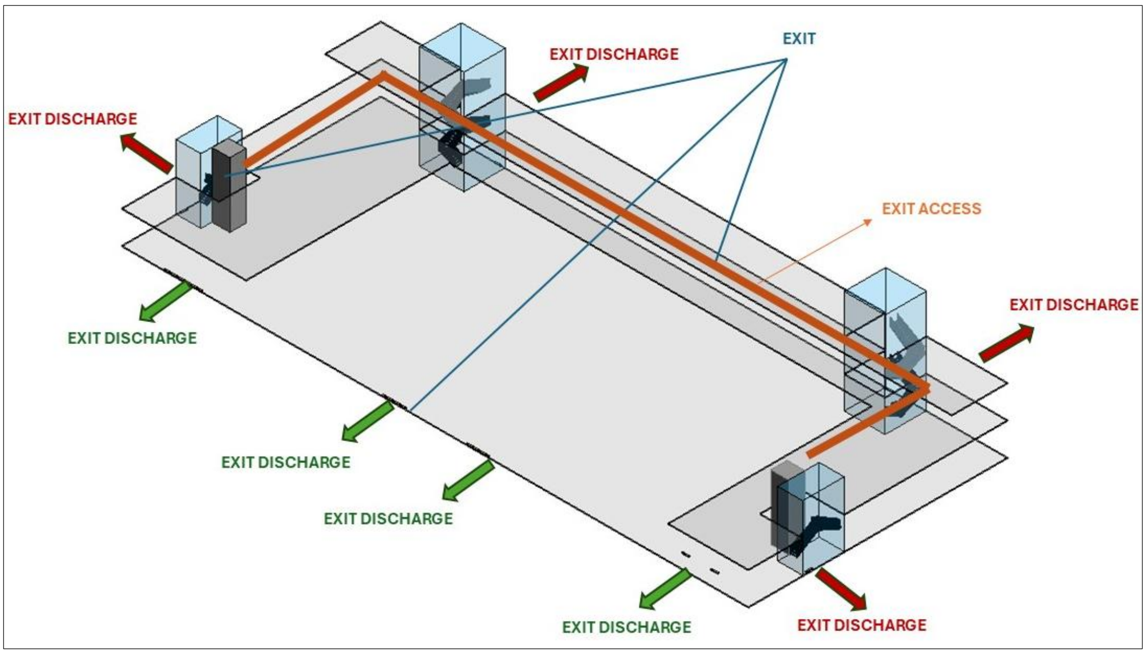


Figure 5.7. Means of egress of the case study

1st floor:

General information and class of use

It consists of 1.983 m² and is at +5.00 level. The floor height is 5 m. As shown in Figure 5.8, there are 7 offices, a meeting room, 2 office rooms, a dining hall, 15 bedrooms, a fitness room, a rest room, a board room and 2 archives. As with the ground floor, the first floor serves different areas of use. According to Article 31/5 of the TRRFP, it is evaluated in the 'Office Buildings' use class.

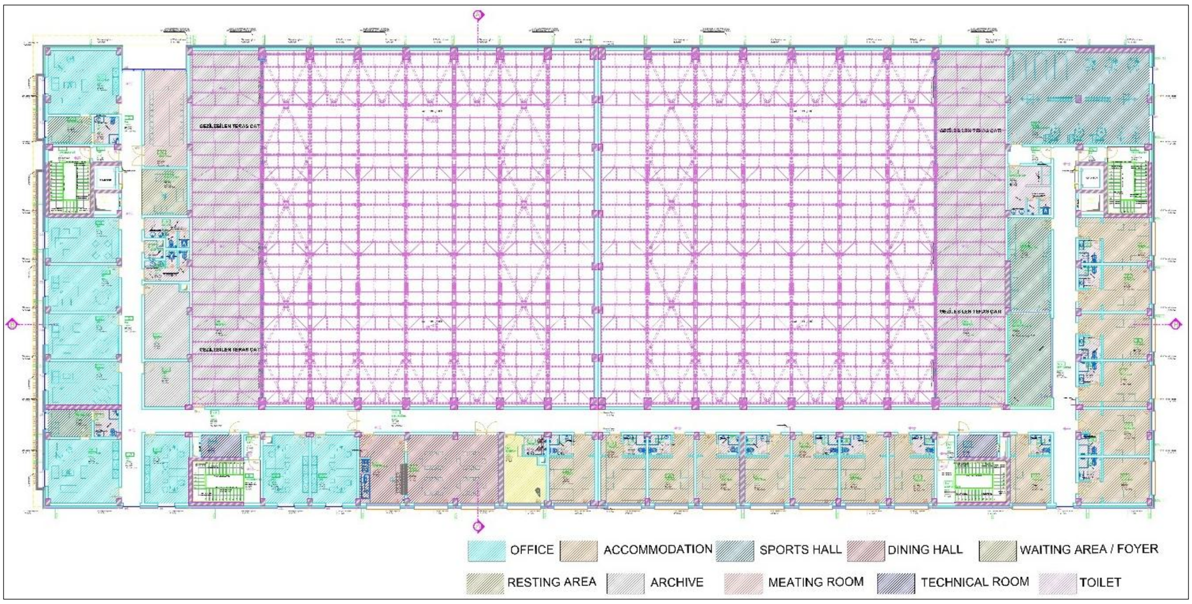


Figure 5.8 Function diagram of the first floor areas of the printing service building

Horizontal escape opportunities

As shown in Figure 5.9, there are fire safety halls and corridors on the ground floor that form the escape route. Users pass through these escape routes, reach the fire safety halls and pass to a safe point.

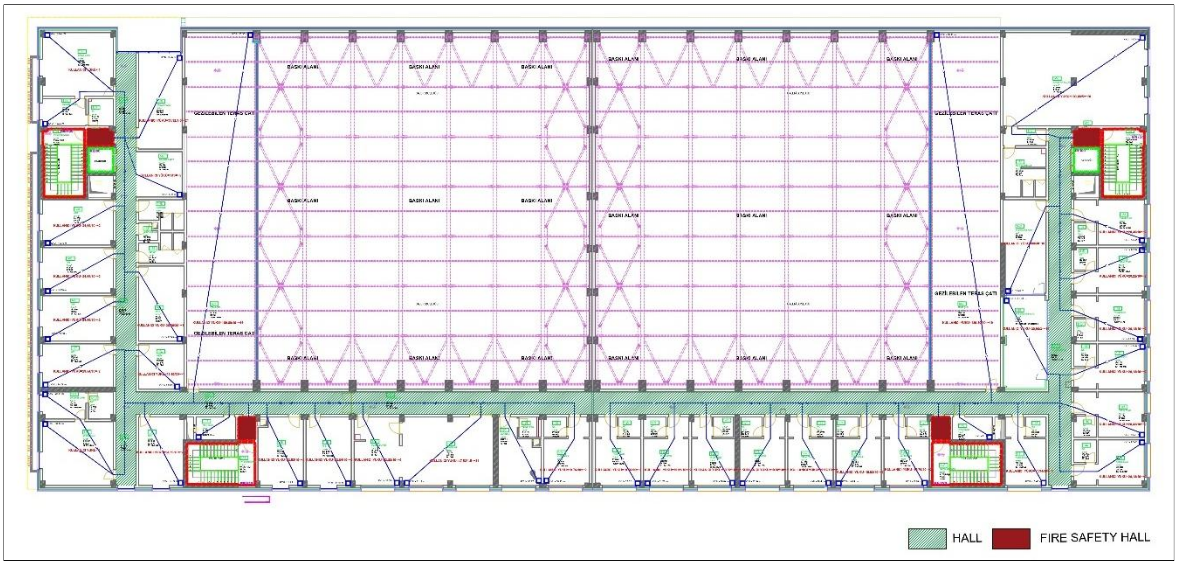


Figure 5.9. Printing service building first floor horizontal escape ways

On the first floor, the escape distance was measured up to the fire safety hall shown in 5.9. The longest escape route is 38 m. In the TRRFP, there is a regulation shown in Table 5.3 that two direction should not exceed 75 m with spring system and single direction should not exceed 30 m. Since the relevant project has a two direction and sprinkler system, the longest escape distances leading to the exits comply with the 75 m regulation. Thus, it is ensured that the users reach a safe area within the appropriate distance.

Table 5.3. Longest escape distances to exits in office buildings (Council of Ministers, 2007)

Class of Use	One direction maximum distance (m)		Two directions maximum distance (m)	
	No sprinkler system	With sprinkler system	No sprinkler system	With sprinkler system
Office Buildings	15	30	45	75

Vertical escape opportunities

As shown in Figure 5.10, there are four fire escape stairs and two elevators on the first floor. When the user load calculation is made in the areas where users can be found on the floor, the overall number of people on the floor is 185; according to Article 39/2 of the TRRFP, at least two exits should be provided.

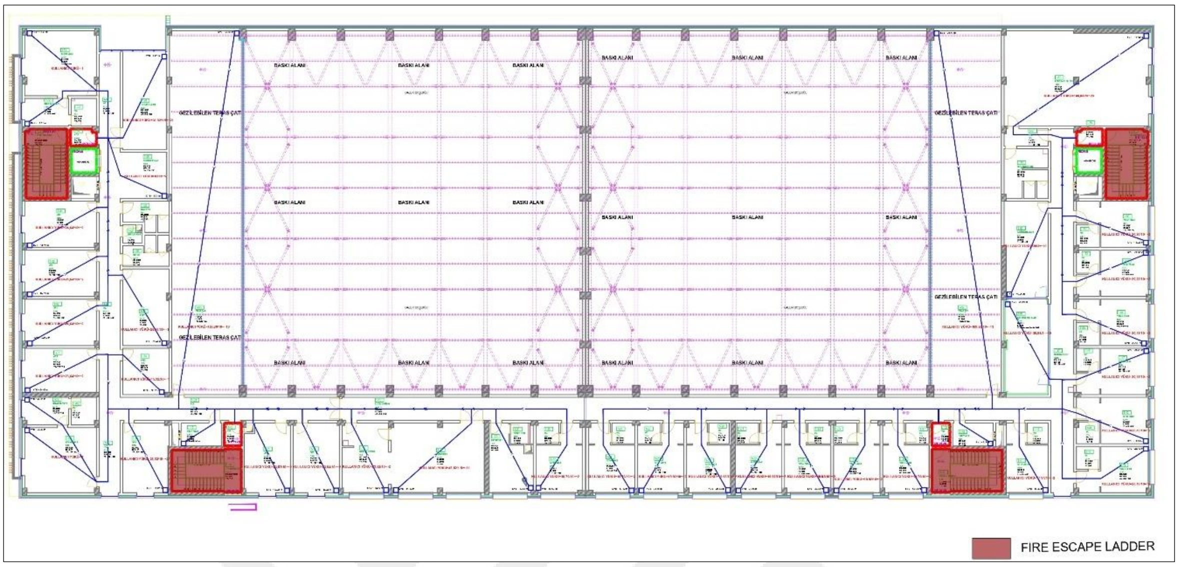


Figure 5.10. Printing service building first floor vertical escape ways

Evacuation strategy

Users on the floor will use the four fire escape stairs; sufficient exit and escape width can be provided. Elevators are not used for escape purposes.

<u>Roof floor:</u>

General information and class of use

It consists of 609 m² and is at +10.00 level. The floor height is 4 m. As shown in Figure 5.11, there is no other use other than technical use on the floor. For this reason, it is classified as “Industrial use” according to TRRFP.

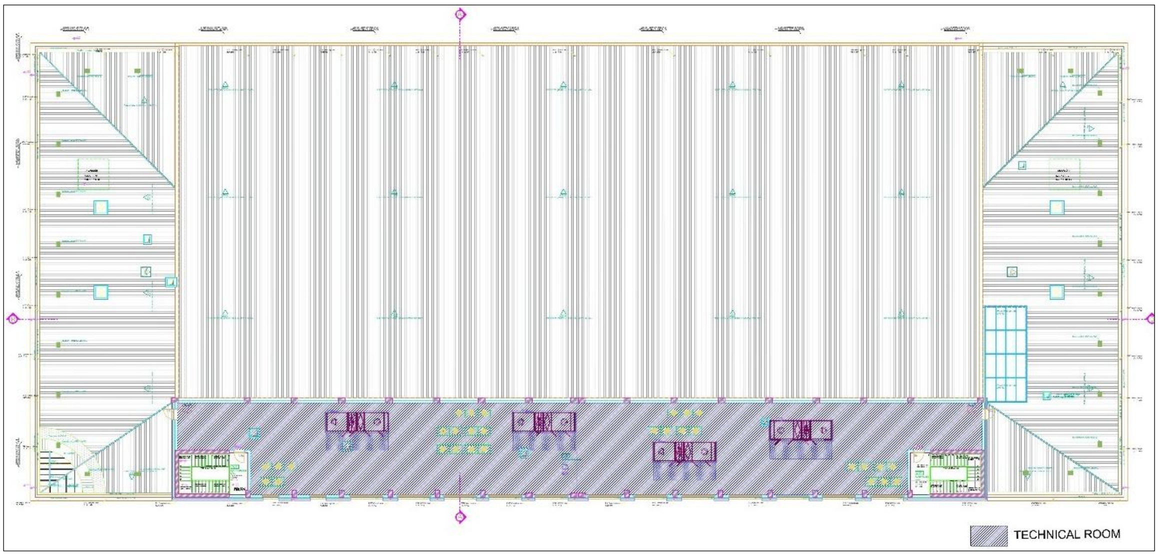


Figure 5.11. Function diagram of the roof floor areas of the printing service building

Horizontal escape opportunities

As shown in Figure 5.12, there is an air conditioning plant room on the roof floor, which forms an escape route. Users pass through these escape routes and reach a safe point.

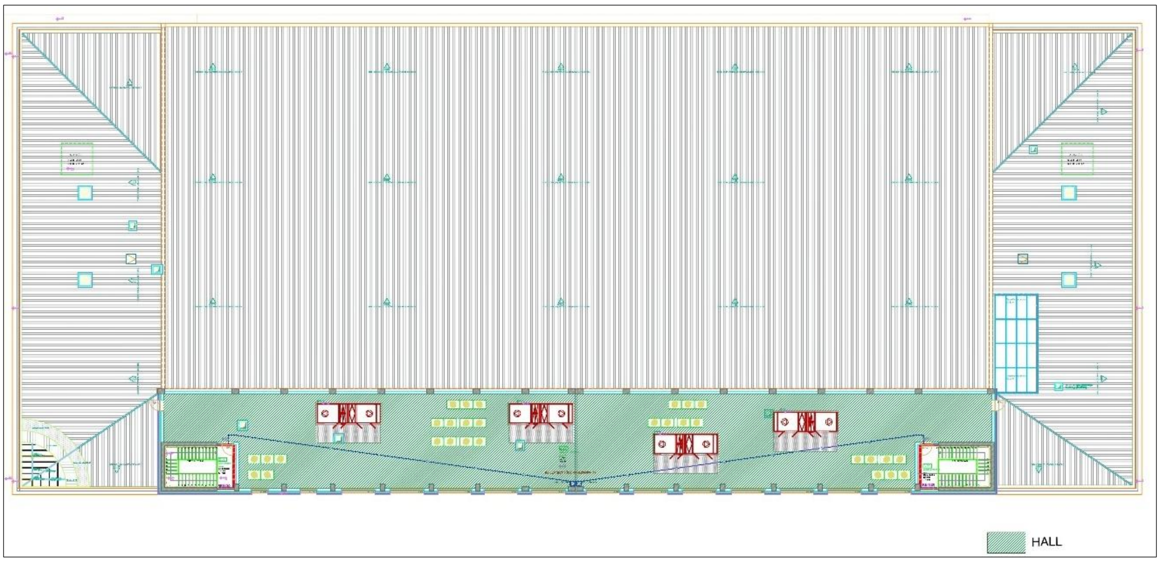


Figure 5.12. Horizontal escape ways in the roof floor of the printing service building

At the roof floor, the escape distance was measured up to the fire escape staircase shown in Figure 5.12. The longest escape route is 30.5 m. According to the TRRFP, there is a regulation that two direction with spring system should not exceed 60 m and single direction should not exceed 25 m. Since the relevant project has a two direction and sprinkler system, the longest escape distances leading to the exits comply with the 60 m regulation. Thus, it is ensured that users reach a safe area within the appropriate distance.

Vertical escape opportunities

As shown in Figure 5.13, there are two fire escape stairs on the attic floor, which are vertical escape facilities. When the user load calculation is made in the areas where users can be found on the floor, the overall number of people on the floor is 18.

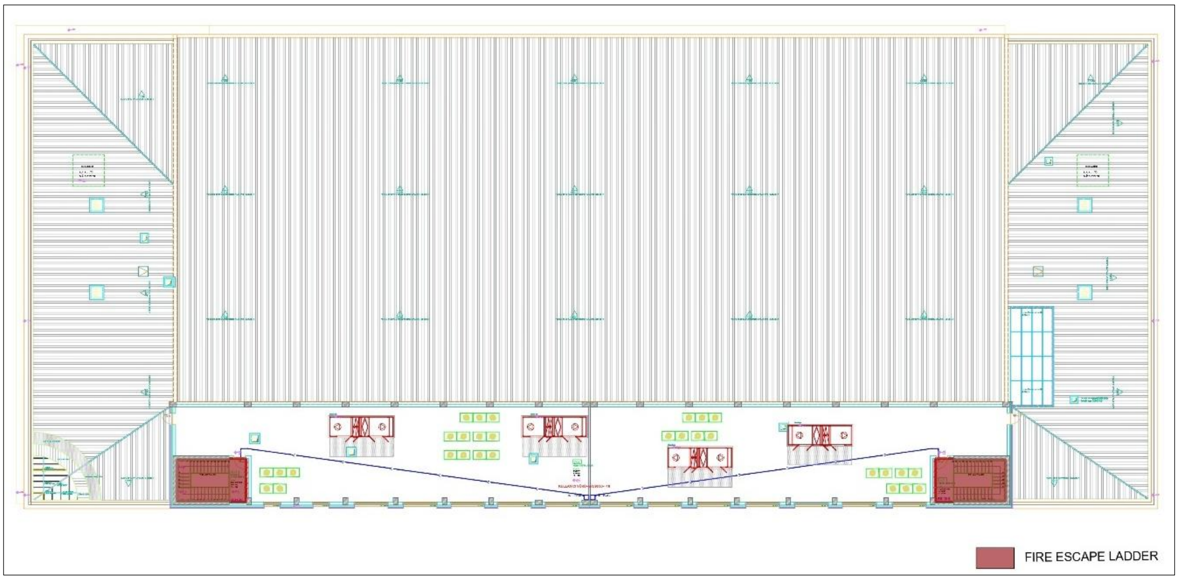


Figure 5.13. Printing service building roof floor vertical escape ways

Evacuation strategy

Users on the floor will use two fire escape stairs; sufficient exit and escape width can be provided.

5.2. Analysis of Escape Evacuation Simulation Programs

Simulation programs are used for planning and analyzing escape routes. These programs are used to analyze the effectiveness and safety of escape routes by simulating the evacuation of building occupants during emergencies such as fire or earthquake. Escape simulation programs:

• Realistic calculation and optimization of evacuation times,
• Identification of critical congestion and density points,
• Numerical testing of the effects of different architectural designs and layouts,
• Creation of realistic scenarios for emergency management and personnel training,
• Conducting effective virtual tests instead of costly and time-consuming physical drills,
• Providing evidence and data for regulatory compliance,
• Creating flexible and comprehensive safety plans through multi-scenario analysis,

as well as the advantages listed above.

In order for evacuation to be quick and safe, buildings should be designed through the design and construction phase to be suitable for evacuation in a safe time. Planning evacuations and creating safety precautions have long been done using simulation models that are accessible through a variety of software programs. It is preferred to carry out the studies during the design phase and to incorporate the results into the design. It is precisely at this point that the importance of fire evacuation simulation programs is understood (Akça, Ceylan, Demirel, 2023). Figure 5.14 shows escape simulation programs and figure 5.15 shows the common features of simulation programs.

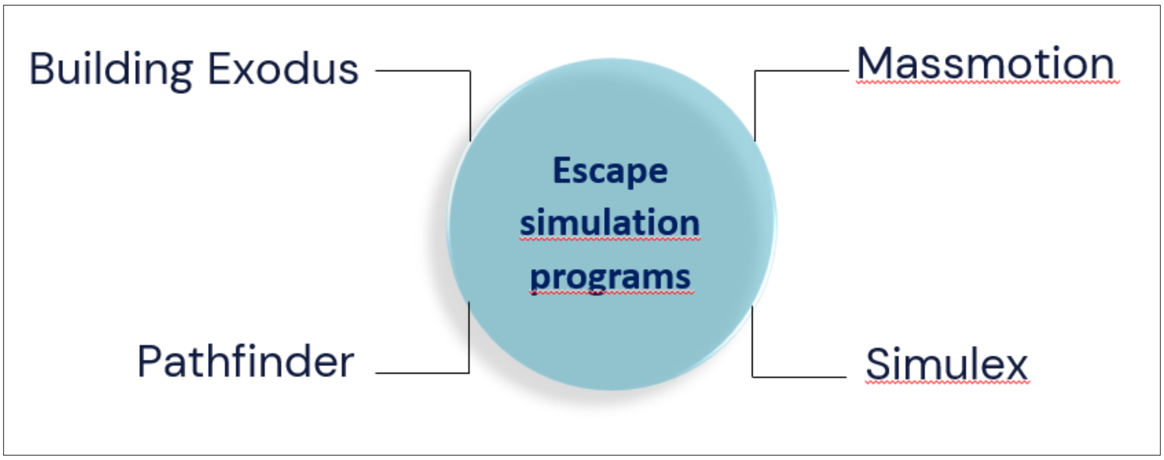


Figure 5.14. Escape simulation programs diagram (Akça, Ceylan, Demirel, 2023)

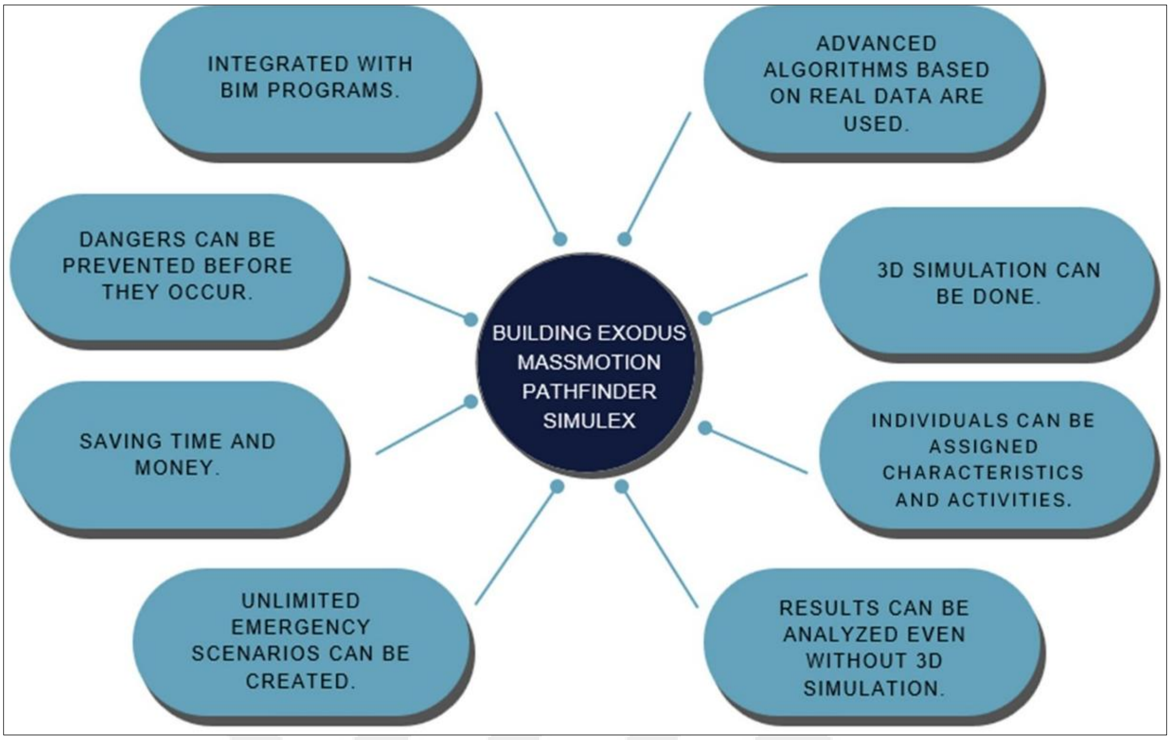


Figure 5.15. Diagram showing the common features of simulation programs (Akça, Ceylan, Demirel, 2023)

5.3. Stages of the Simulation of the Case Study

The scale of the printing service building is adjusted after the floor plans of the architectural project worked with AutoCAD format are loaded into the Pathfinder simulation program. Doors, stairs, elevators, rooms and exits placed according to the architectural project are modeled as planar. User load data is entered into the simulation program. Occupants are added by selecting the user profile and finally the simulation is run. Figure 5.16 shows the stages of creating a simulation of the project selected as a sample in Pathfinder.

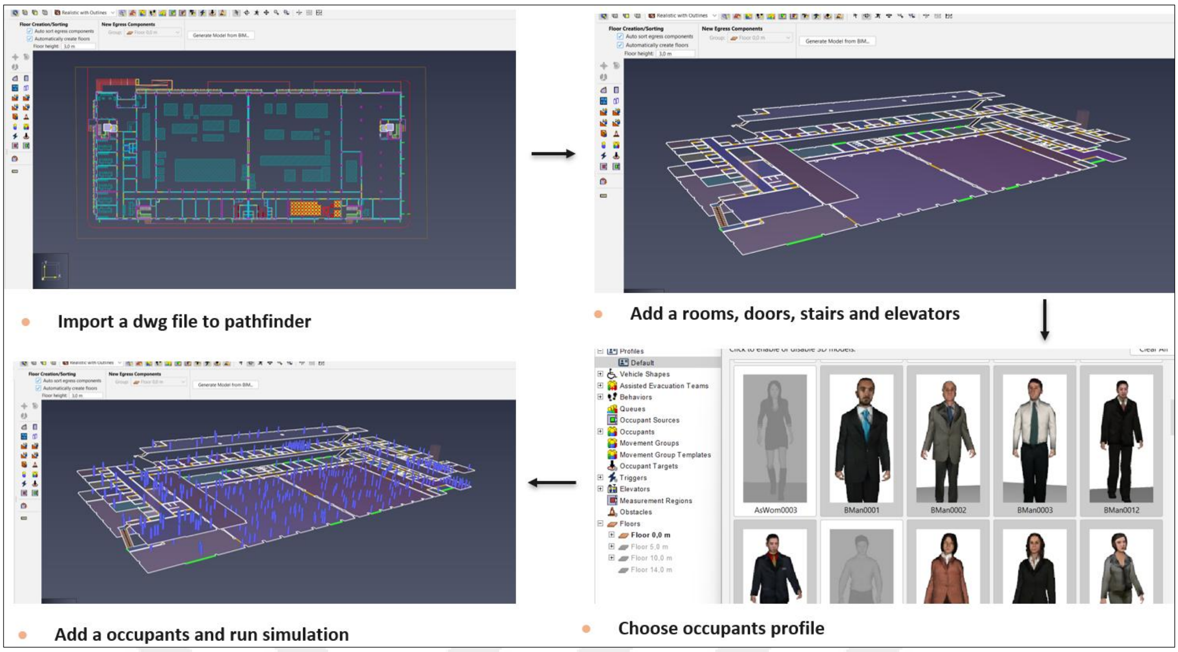


Figure 5.16. Stages of generating the case study in Pathfinder

5.4. Simulation of Escape Evacuation of the Case Using the "Pathfinder" Program

In this thesis, the escape simulation of the printing service building in Ankara, which is selected as a case study, is evaluated with the performance-based Pathfinder motion simulation program method. The primary aim of the modeling is to provide that all users of the building are evacuated within the time that they can safely leave the building. Evacuation simulations provide guidance for the calculation of the evacuation time as well as the identification of risk areas that need to be considered during the creation of industrial building and evacuation plans. Image 5.3 shows an example project with Pathfinder.

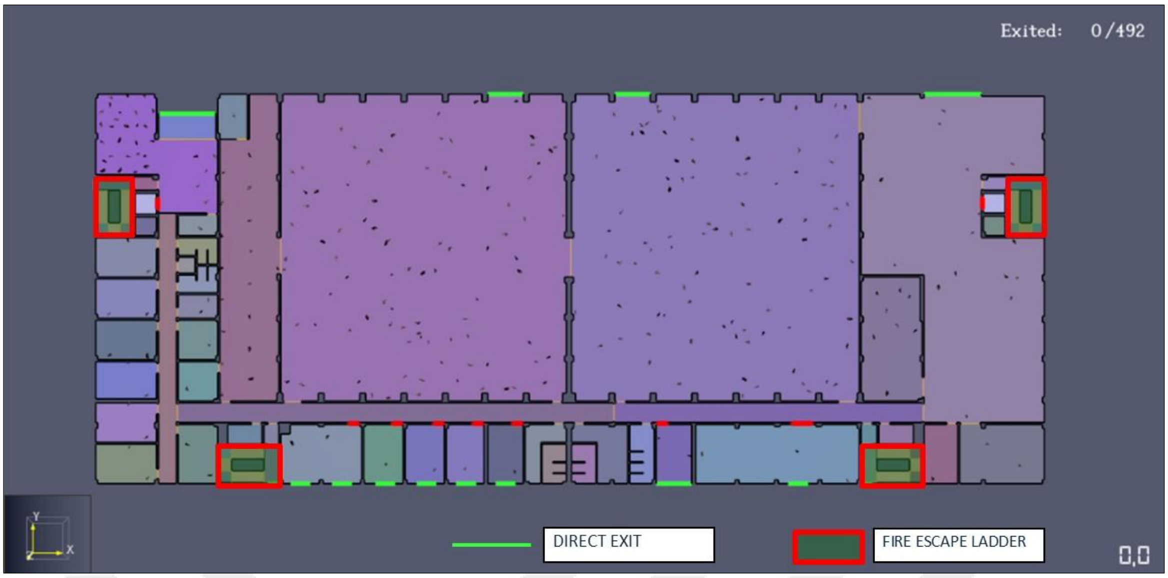
(a) (b)

Image 5.3.a,b. Pathfinder images of sample projects (URL-17)

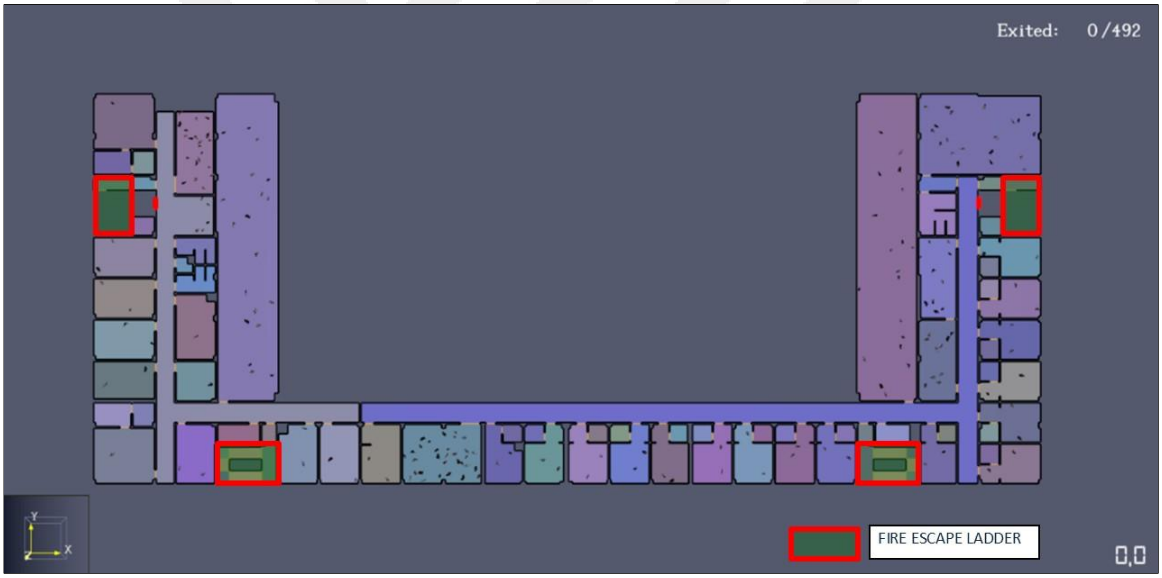
Pathfinder, created by Thunderhead Engineering, was utilized to model the sample's evacuation. Pathfinder provides comprehensive metrics including density, speed, and person flow rates and is renowned for its sophisticated modeling of human movement during emergencies. It is a useful tool for evaluating evacuation effectiveness because of its capacity to replicate various emergency situations. Its drawbacks, however, include the presumption that all passengers behave consistently, which does not fully represent the range of reactions and exchanges seen in actual events (Godes et al., 2024).

The Pathfinder simulation program is able to manage users' speed variables, accessibility to exits and profile, as well as users' behavior, movement orientation and choice, among others. Pathfinder supports two motion simulation modes, SFPE mode and orientation mode. The mode used in this analysis is routing mode. Users use a “steering mode” to move and interact with other users; unlike SFPE mode, users pay attention to blockers, walls and other users. Users have the ability to deviate from their path to overcome an obstacle as they move towards completing their movement. In this way, users respond to a changing and dynamic environment. As a result, the guidance mode was chosen because it tries to mimic human behavior and movement as much as possible. In this analysis, smoke density, smoke spread rate and fire design were not taken into account (Thunderhead Engineering Consultants, 2022; Özdamar, 2020).

After entering the occupant load data, the simulation program automatically randomly placed the occupants in the rooms as shown in Figure 5.17. Figure 5.18 shows the 3D view of the floors at 5.8 s and the path representation of the occupants. Figure 5.19 shows the 3D view of the floors at s 13.6 and the speed distribution of the occupants.

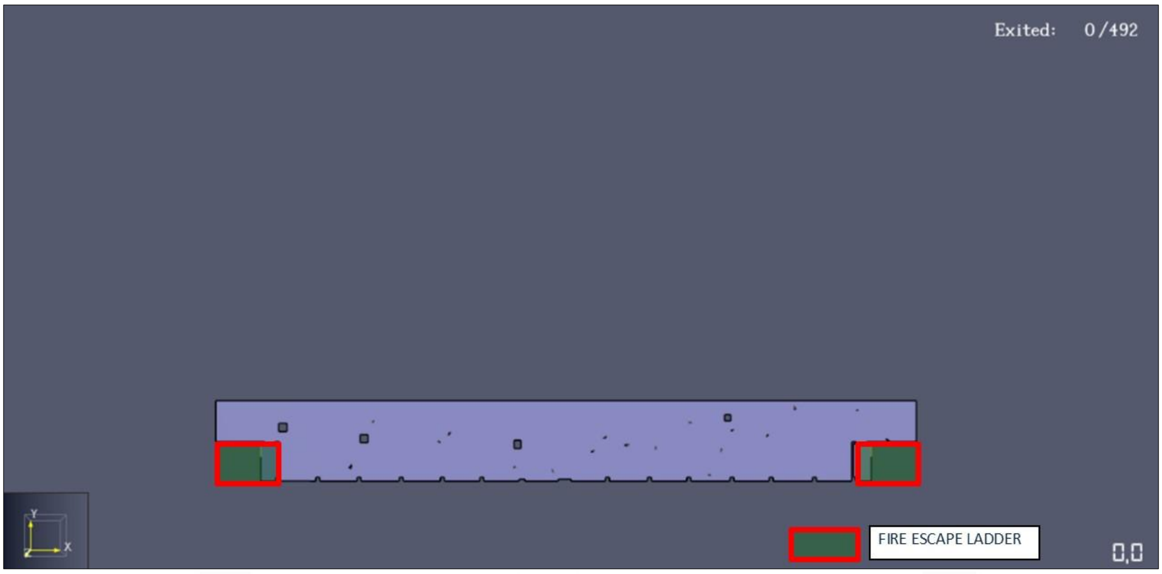


(a) Ground floor



(b) First floor

Figure 5.17. a. Ground floor b. First floor c. Roof floor
The view when the users in the rooms are randomly distributed



(c) Roof floor

Figure 5.17. (Continued) a. Ground floor b. First floor c. Roof floor
The view when the users in the rooms are randomly distributed

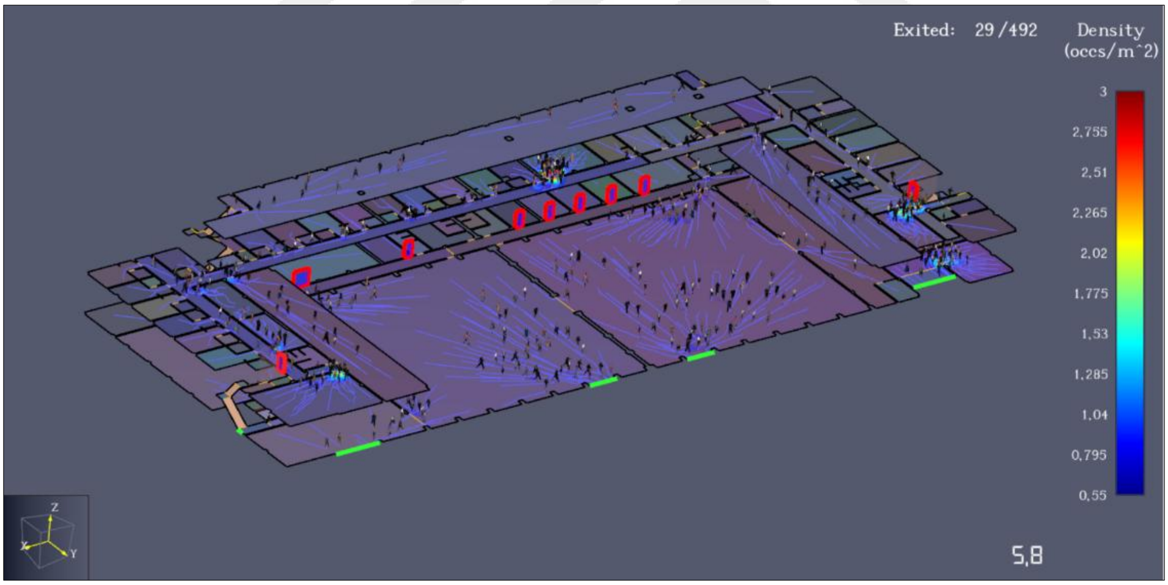


Figure 5.18. 3D view of floors at 5.8 s and occupant path display

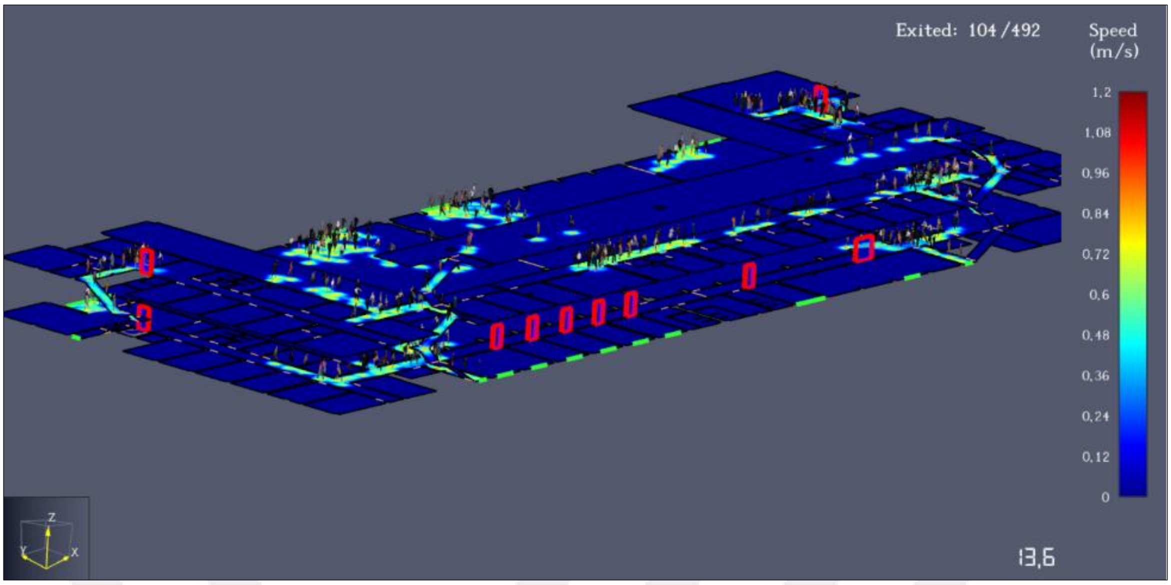


Figure 5.19. 3D view of the floors at 13.6 s and speed distribution of occupants

Figure 5.20 shows the distribution of occupants on the ground floor 41.7 seconds after the evacuation started. It can be seen that the occupants headed towards all vertical and horizontal escapes.

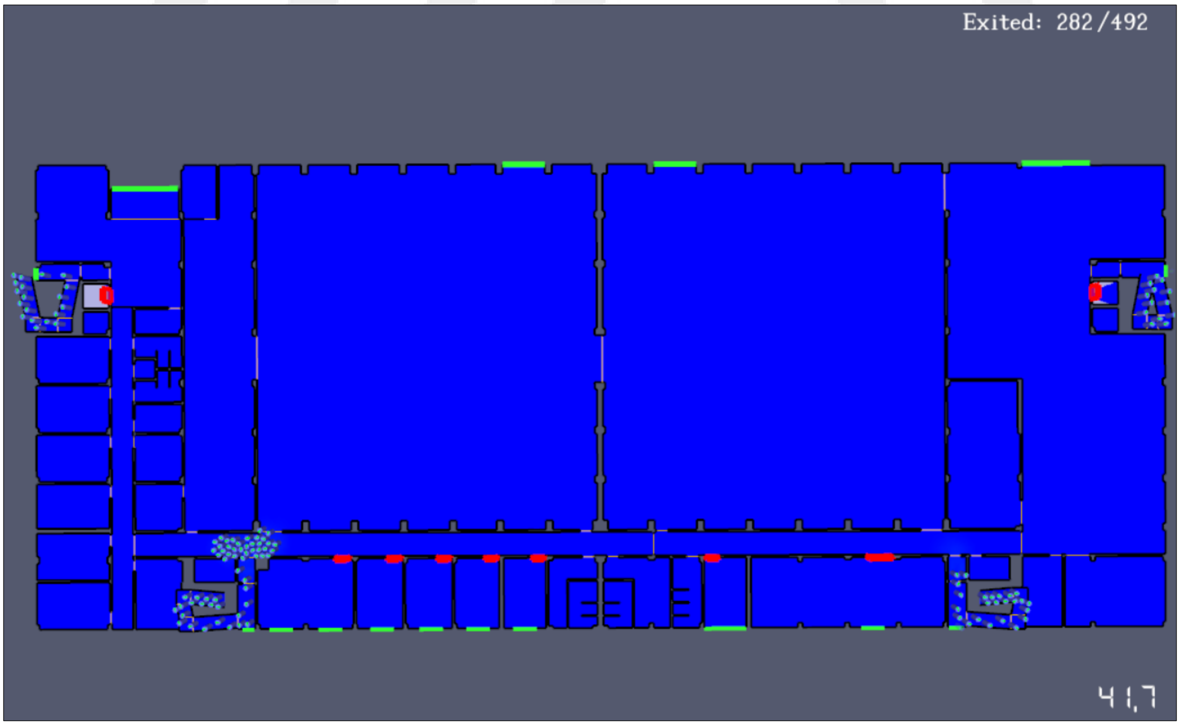


Figure 5.20. Distribution of the number of occupants on the ground floor at 41.7 seconds after the evacuation started

Figure 5.21 shows the distribution of occupants on the first floor 28 seconds after the evacuation started. It is seen that the occupants are oriented towards all vertical and horizontal escapes.

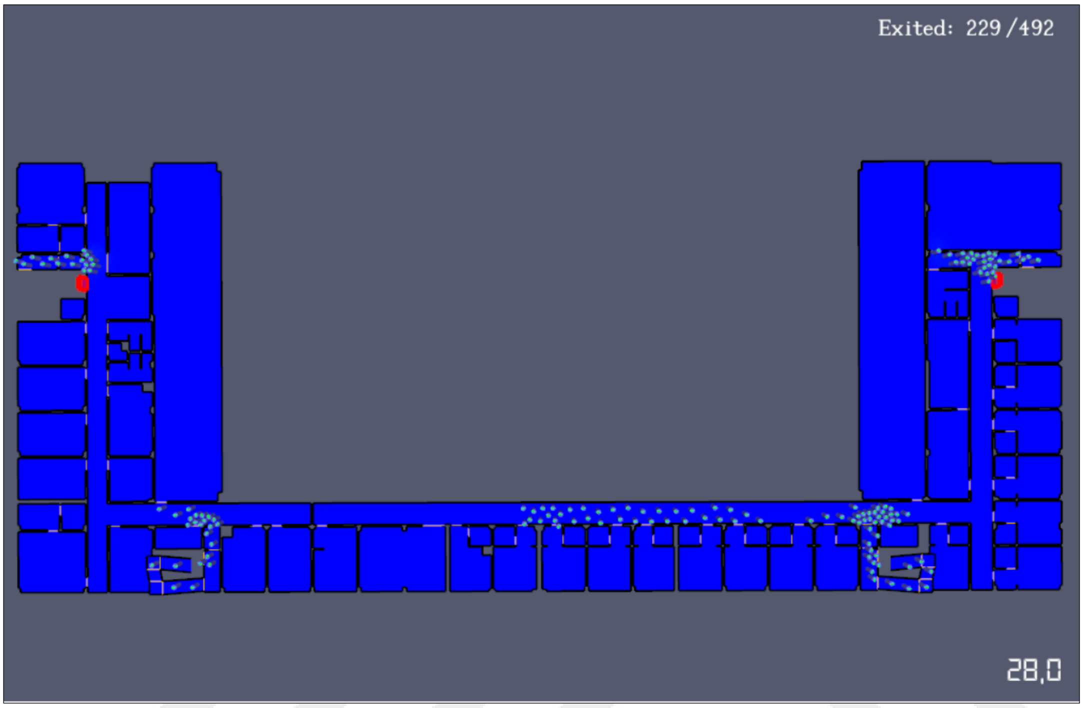
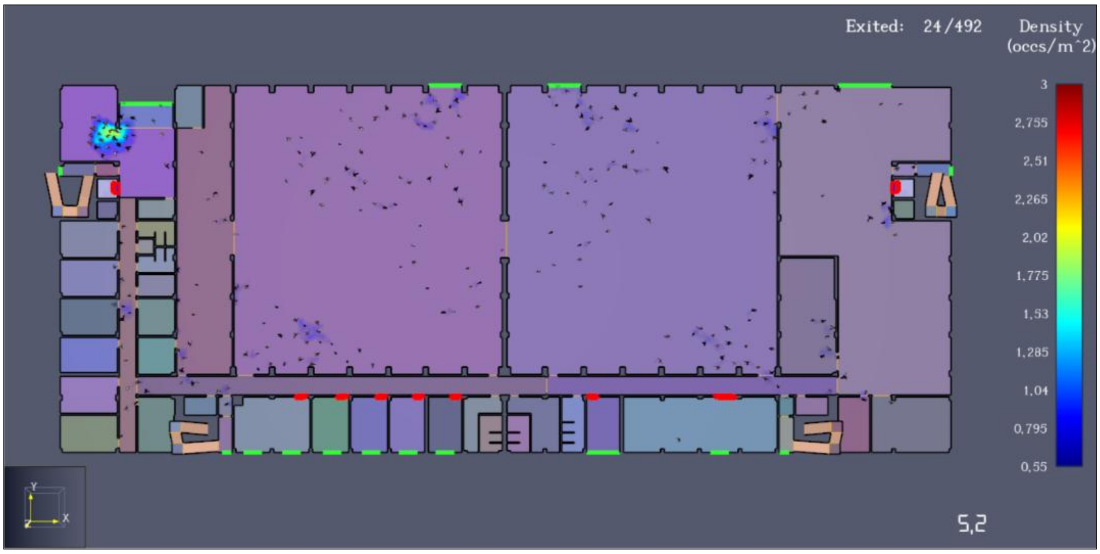
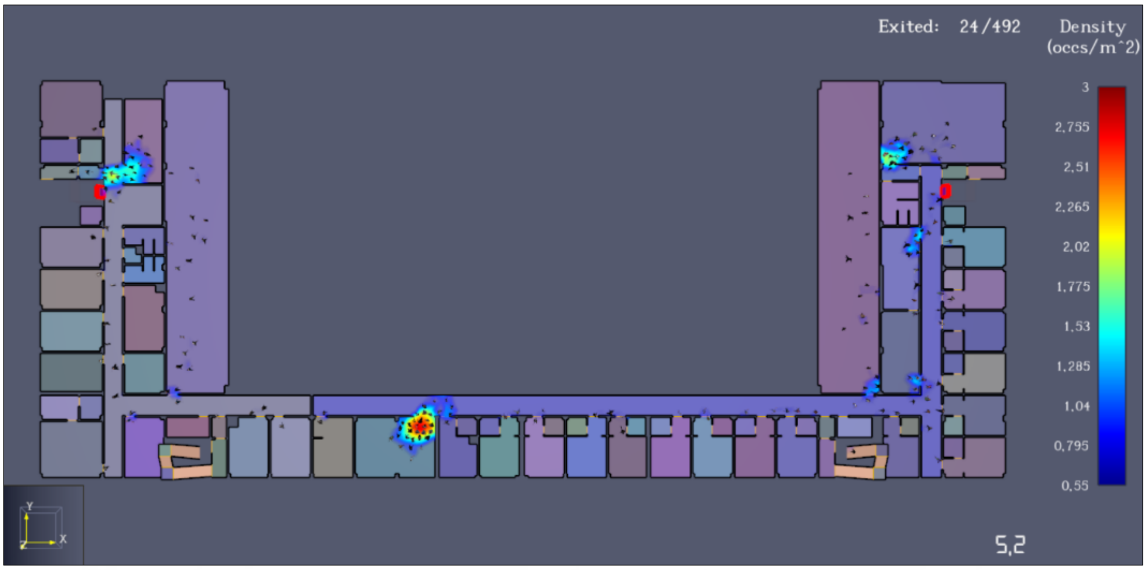


Figure 5.21. Distribution of the number of occupants on the first floor at 28 seconds after the evacuation started

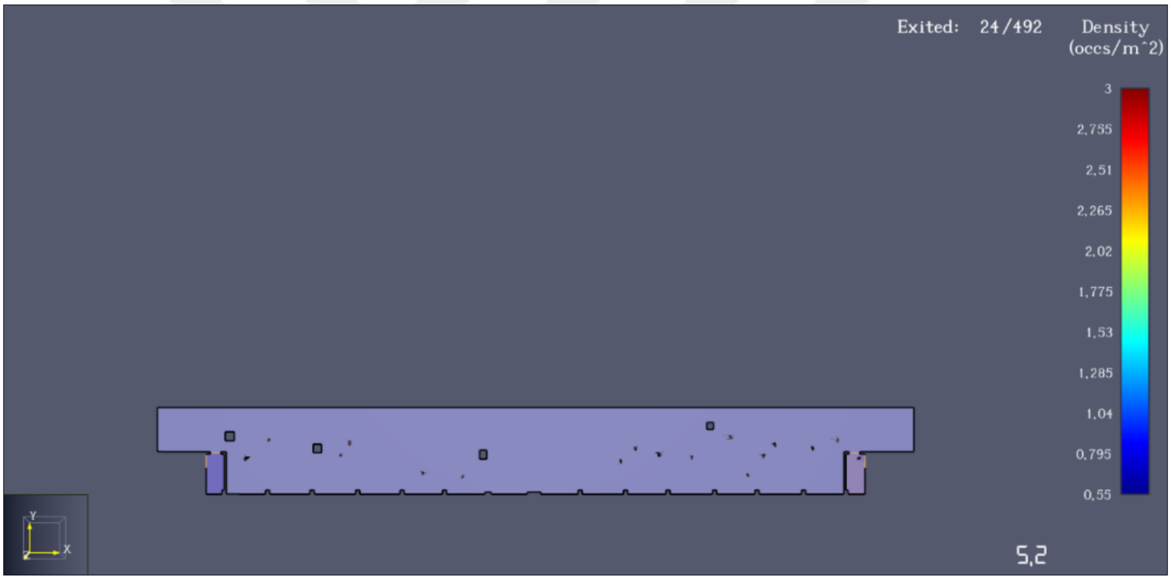


(a) Ground floor

Figure 5.22. a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 5.2 s

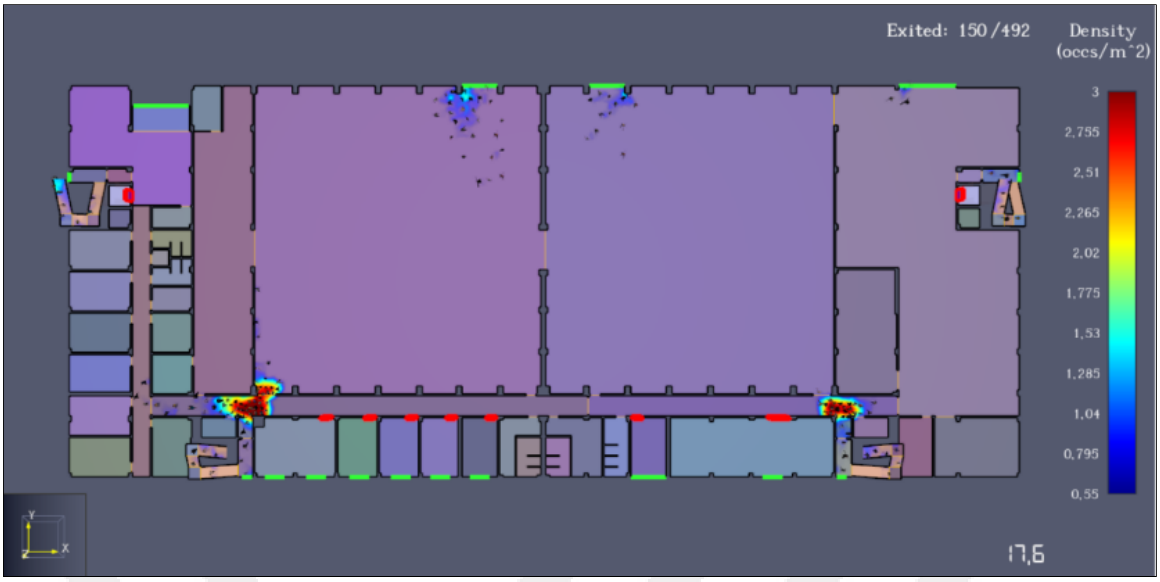


(b) First floor

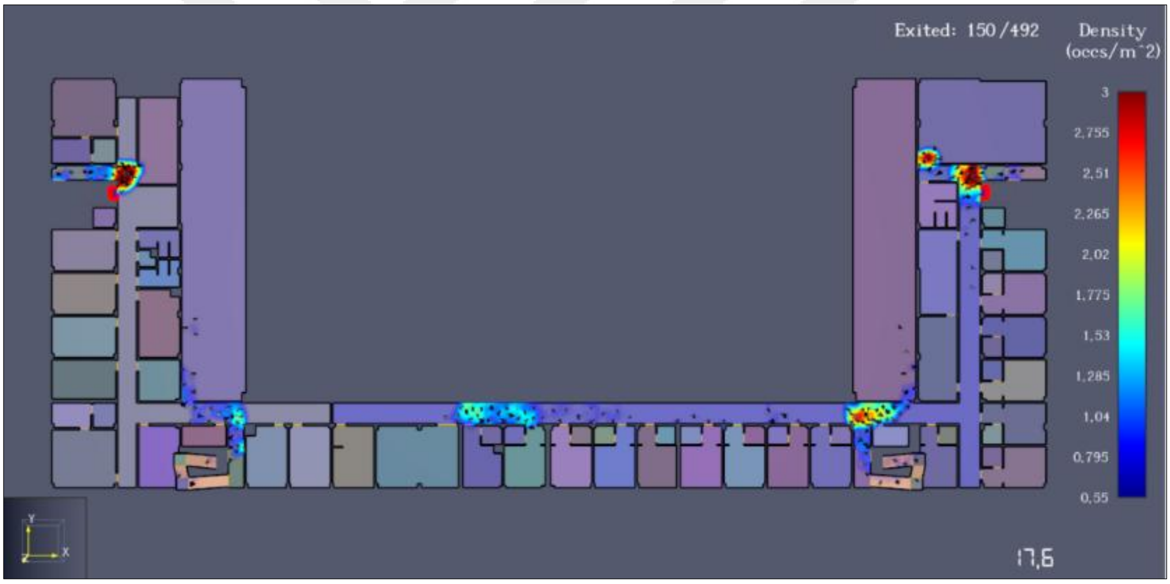


(c) Roof floor

Figure 5.22. a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 5.2 s

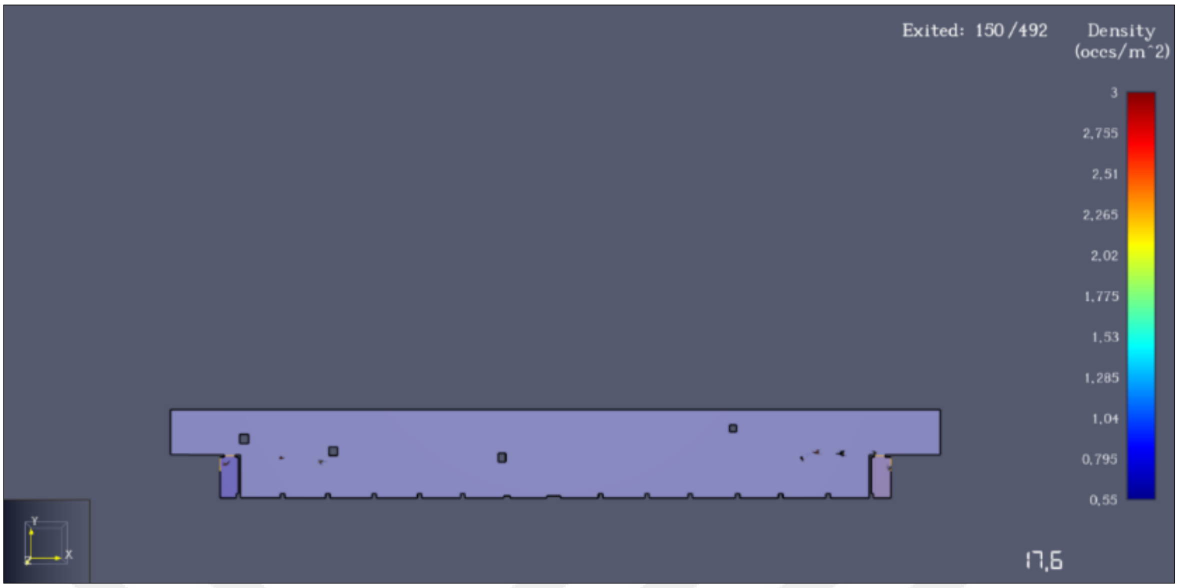


(a) Ground floor



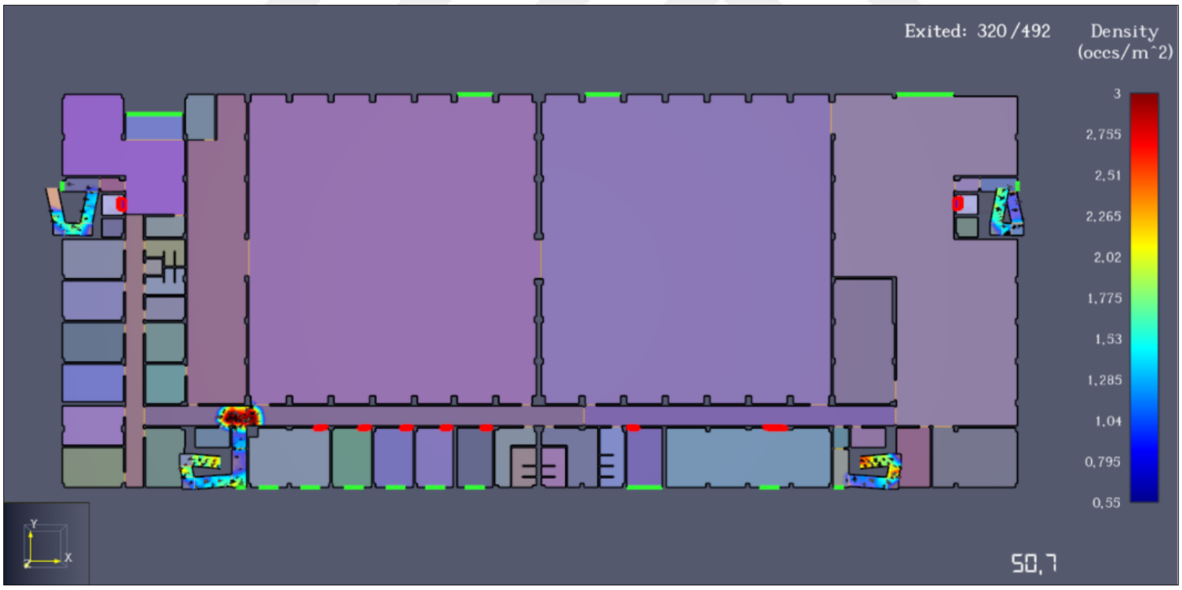
(b) First floor

Figure 5.23. a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 17.6 s



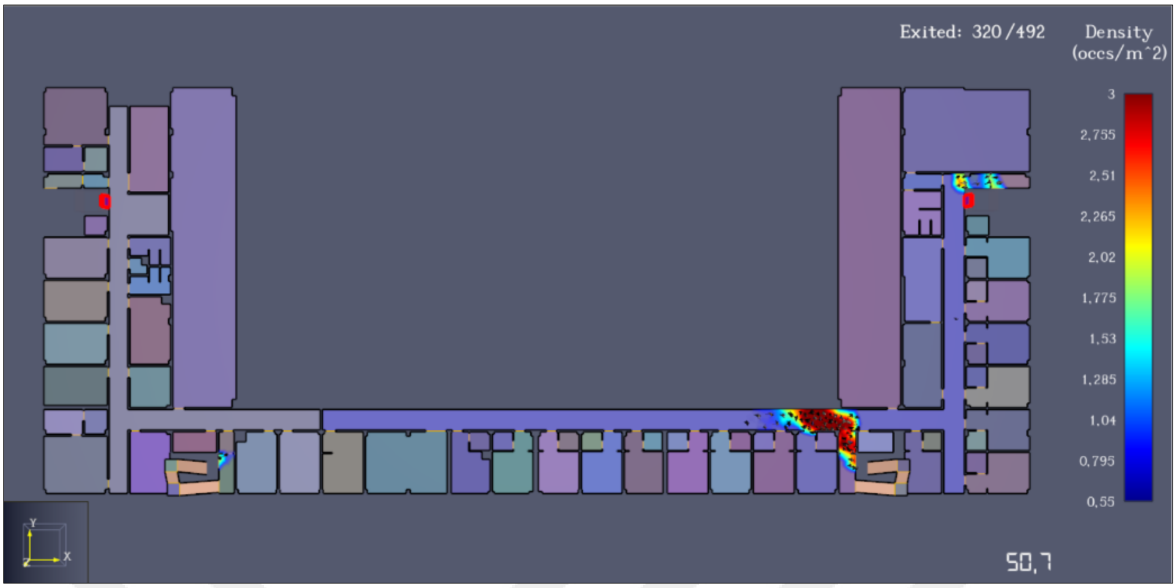
(c) Roof floor

Figure 5.23. (Continued) a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 17.6 s

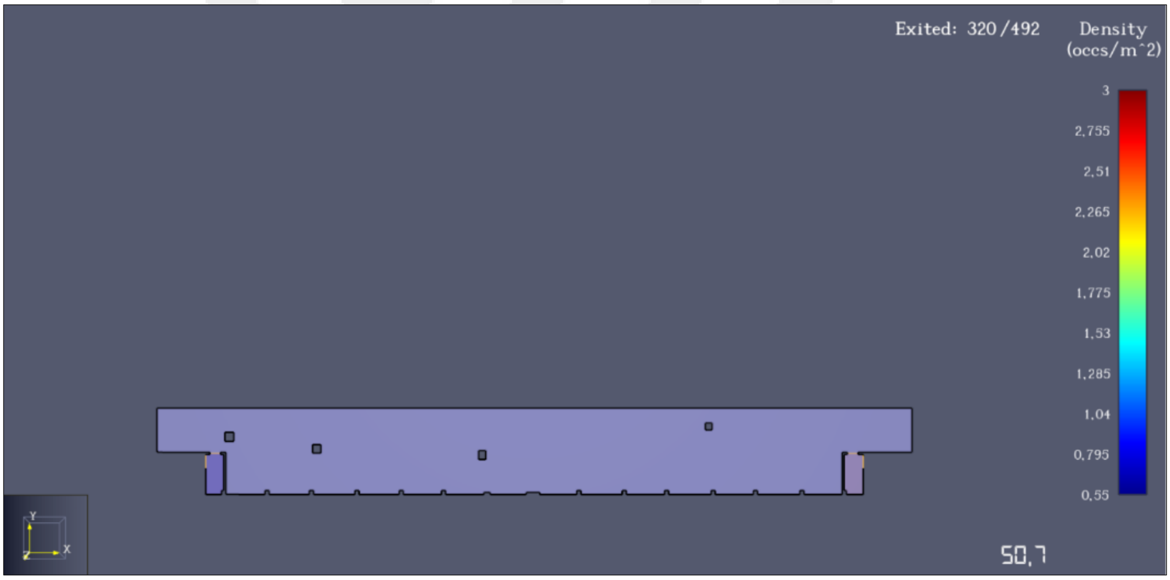


(a) Ground floor

Figure 5.24. a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 50,7 s

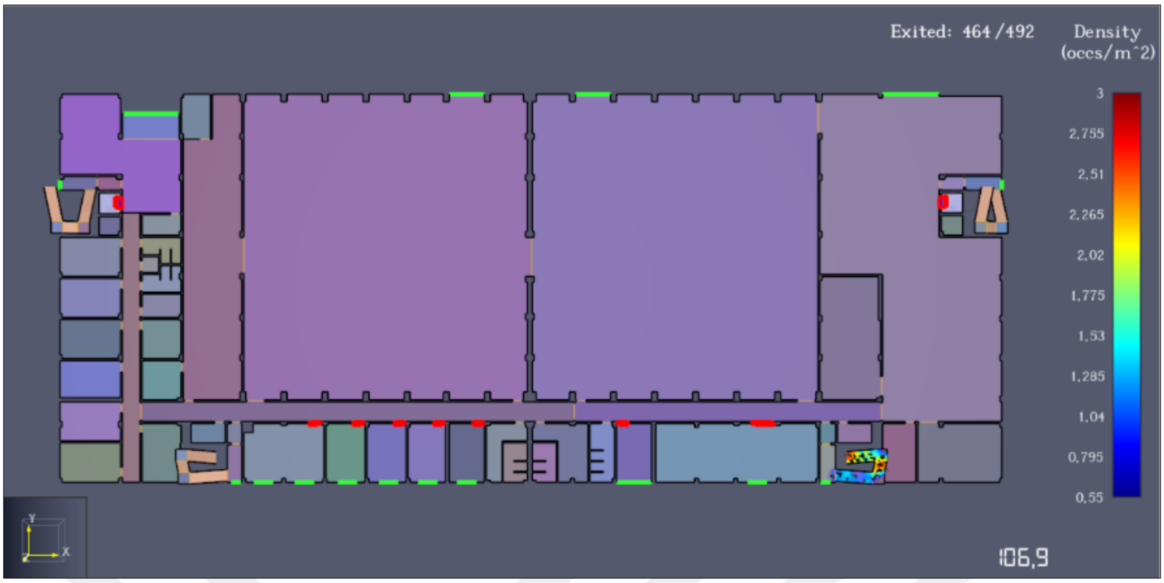


(b) First floor

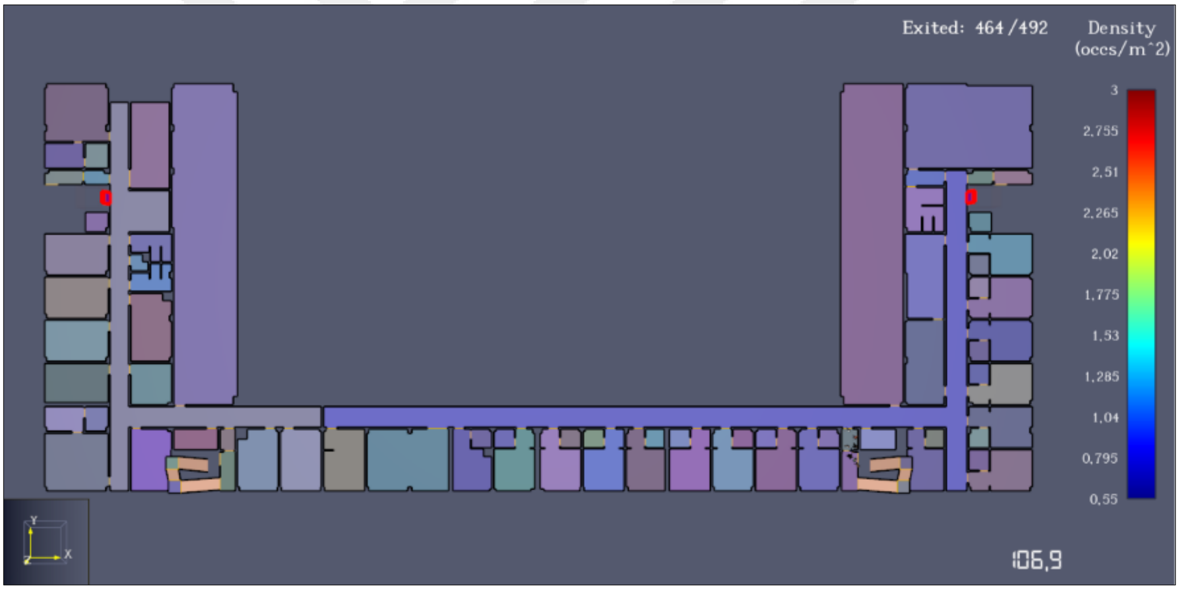


(c) Roof floor

Figure 5.24. (Continued) a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 50,7 s

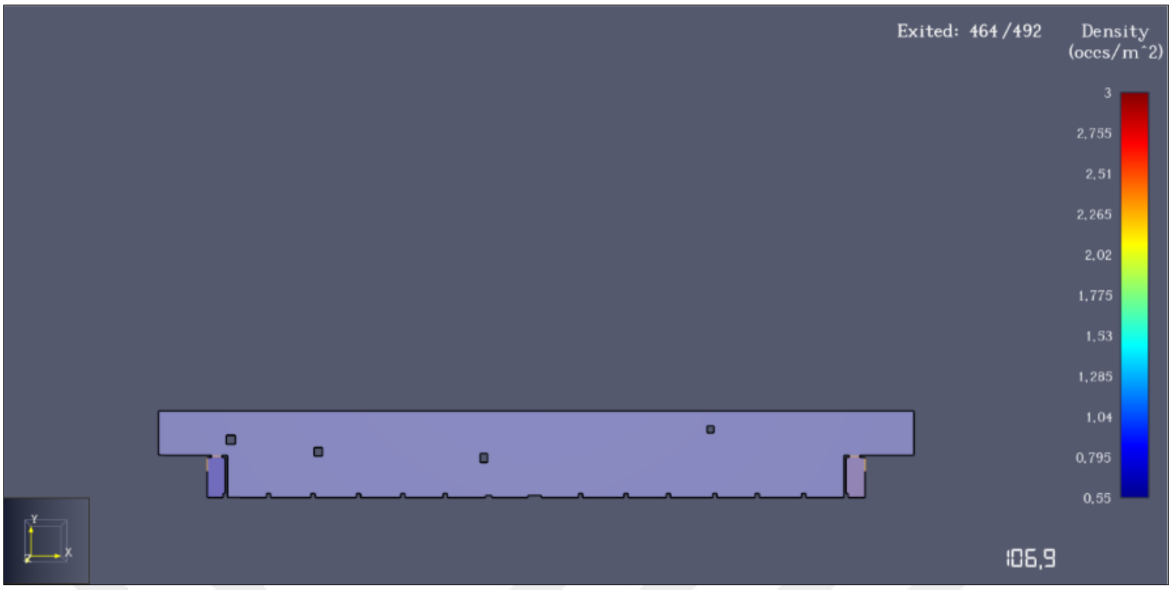


(a) Ground floor



(b) First floor

Figure 5.25. a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 106,9 s



(c) Roof floor

Figure 5.25. (Continued) a. Ground floor b. First floor c. Roof floor
Diagrammatic representation of the flow rate of occupants at 106,9 s

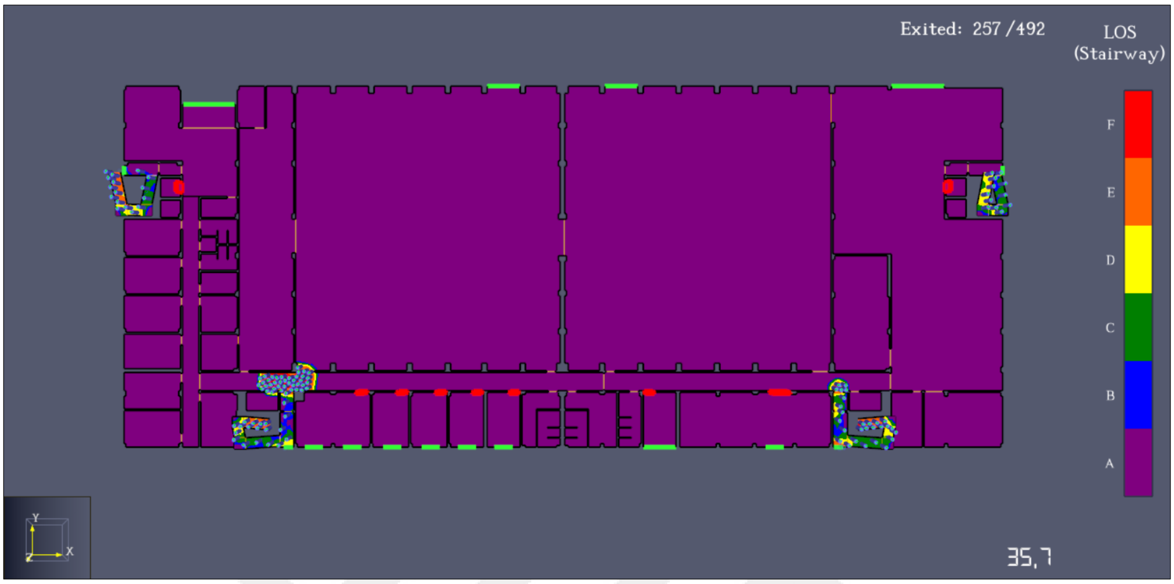
The plans in Figures 5.22, 5.23, 5.24 and 5.25 show the effect of user density on the structure by applying the density parameter, which is the user contour, to the distribution at 5.2, 17.6, 50.7 and 106.9 seconds of the evacuation process, respectively.

According to the plan in Figure 5.22, traffic behind the first-floor exit door grows dramatically at 5.2 seconds. These high-density regions are indicated in red and have an evacuation flow rate of more than three persons per square meter in the escape route. While the color spectrum changes from blue to yellow and finally to red to indicate increasing density, low-density populations are displayed in blue.

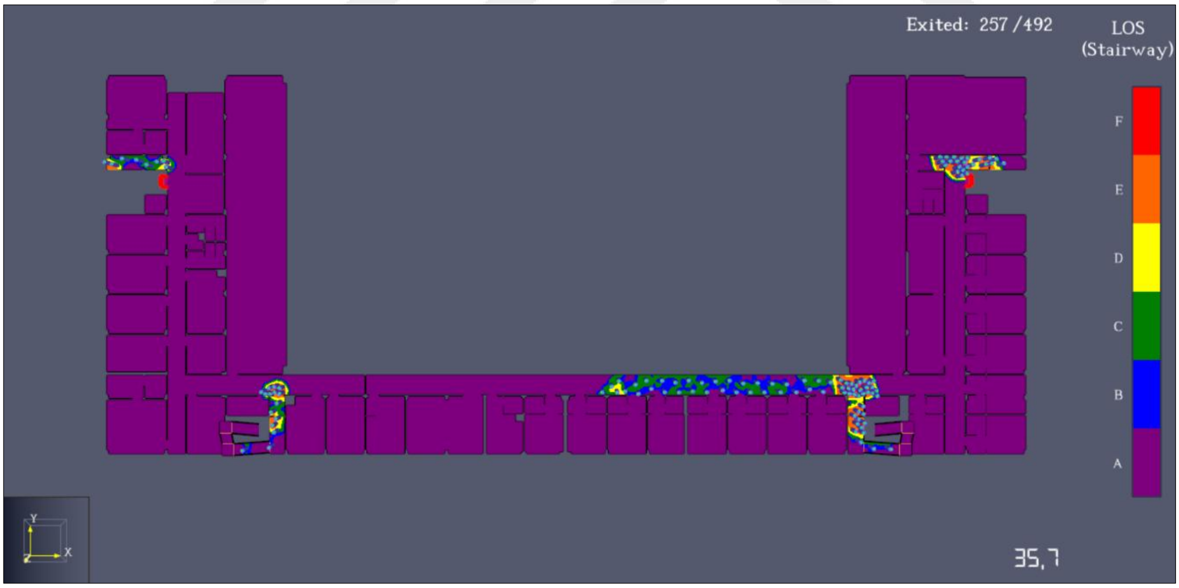
The corridors serving the floors, fire escape stairs and fire safety halls have the maximum density of users (Figure 5.26). The reason for the high density of escape stairs and halls is that they are accessed through a single door. As a result, the user density is at maximum level in these areas; therefore, the user density is shown in dark red.

High intensity evacuation on the ground floor and first floor stairs continues until 50.7 seconds (Figure 5.24).

At 106.9 seconds, occupants evacuate from the first floor and pass by the ground floor stairs with high intensity (Figure 5.25).



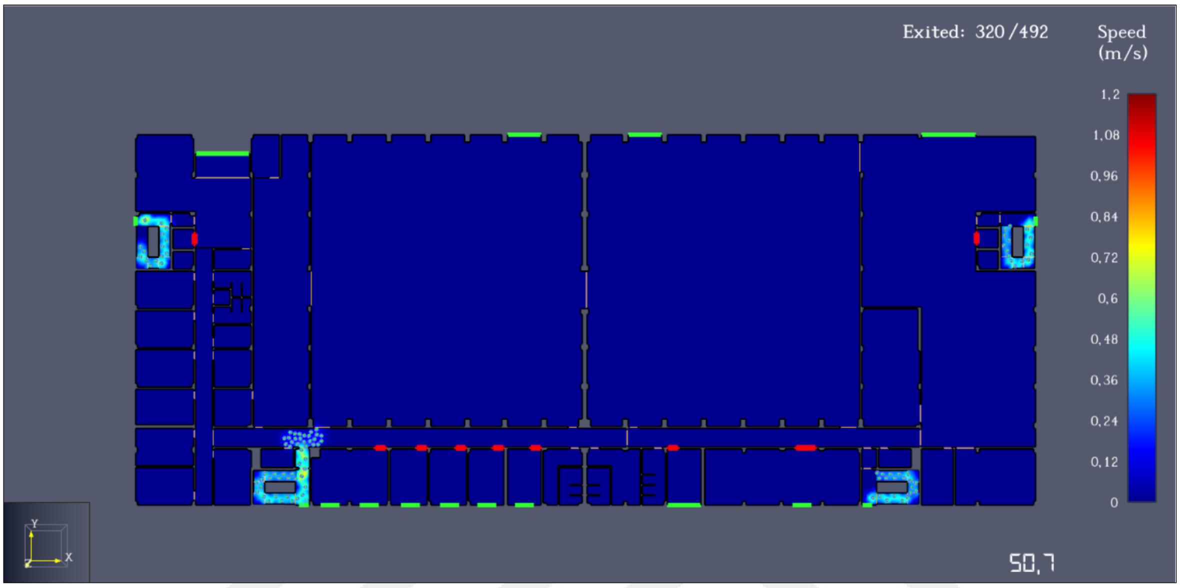
(a) Ground floor



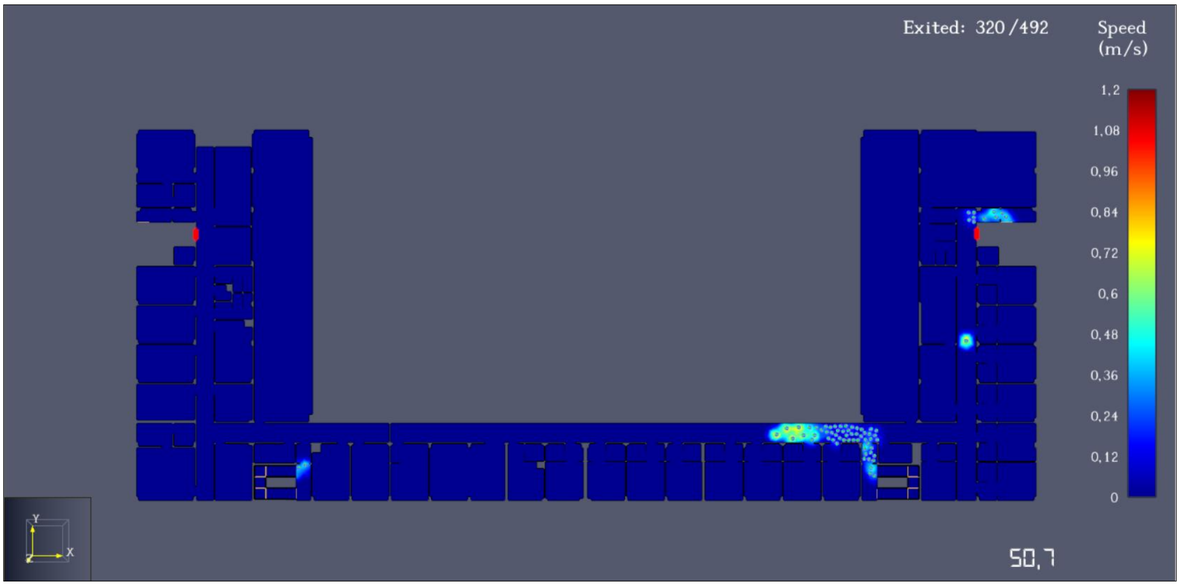
(b) First floor

Figure 5.26. a. Ground floor b. First floor
Level of occupant density on the staircase at 35.7 seconds after the evacuation started

In Figure 5.27, at 50.7 seconds into the evacuation process, the speed parameter, which is the user contour, is applied to the user distribution on the plan to determine the speed distribution of each user. As can be seen in the legend, the color scale ranges from minimum (dark blue) to maximum (dark red); each color scale represents the user speed. There is an inverse relationship between the user density parameter and the speed parameter; in areas with maximum user density, users are unable to move and their speed is 0 m/s.



(a) Ground floor



(b) First floor

Figure 5.27. a. Ground floor b. First floor c. Roof floor
Speed distribution of the number of occupants on the floors at 50.7 seconds after the evacuation starts

(c) Roof floor

Figure 5.27. (Continued) a. Ground floor b. First floor c. Roof floor
Speed distribution of the number of occupants on the floors at 50.7 seconds after the evacuation starts

As a result; escalators, fire safety halls and their surroundings are areas where users congregate and queue; speed parameter analysis shows that users cannot move in these areas and start to wait.

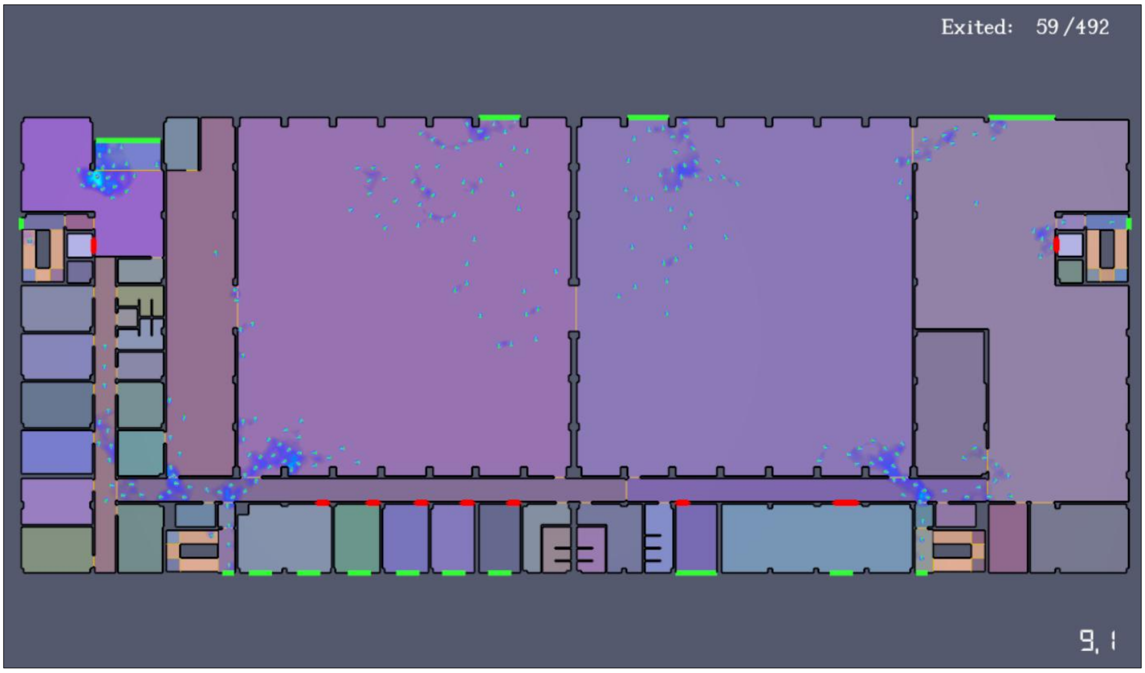


Figure 5.28. Distribution of the number of occupants on the ground floor at 9.1 seconds after the evacuation started

Figure 5.28 shows the distribution of the ground floor occupants on the plan 9.1 seconds after the evacuation strted. It is seen that users do not use all vertical and horizontal escapes; 59 users use direct exits but not fire escape stairs. After 9.1 seconds, users also evacuate by fire escape stairs.

5.5. Evaluation of Simulation Data

In this thesis, the case study selected for the preparation of an escape simulation of an industrial building is a printing press building planned for construction in Ankara. The escape routes and evacuation times of the building were modeled using the 'Pathfinder' software by analyzing the evacuation time with a performance-based fire escape simulation program.

Figure 5.29 demonstrates the number of users in the printing service building according to the time measured from the moment the evacuation begins to the moment it ends. The evacuation process ends after 139.3 seconds (2.3 min), when the last user in the building is evacuated (Figure 5.30). The graph below also shows the evacuation performance and the progress of the evacuation. This graph divides the entire evacuation process into three parts. It shows that there are 25, 90 and 139 seconds from the start of the evacuation. At these time points, it is observed that the evacuation speed slows down due to bottleneck congestion. However, when the graph is analyzed overall, the fact that the number of users decreases immediately after the evacuation begins indicates that users do not encounter any obstacles during the evacuation process.

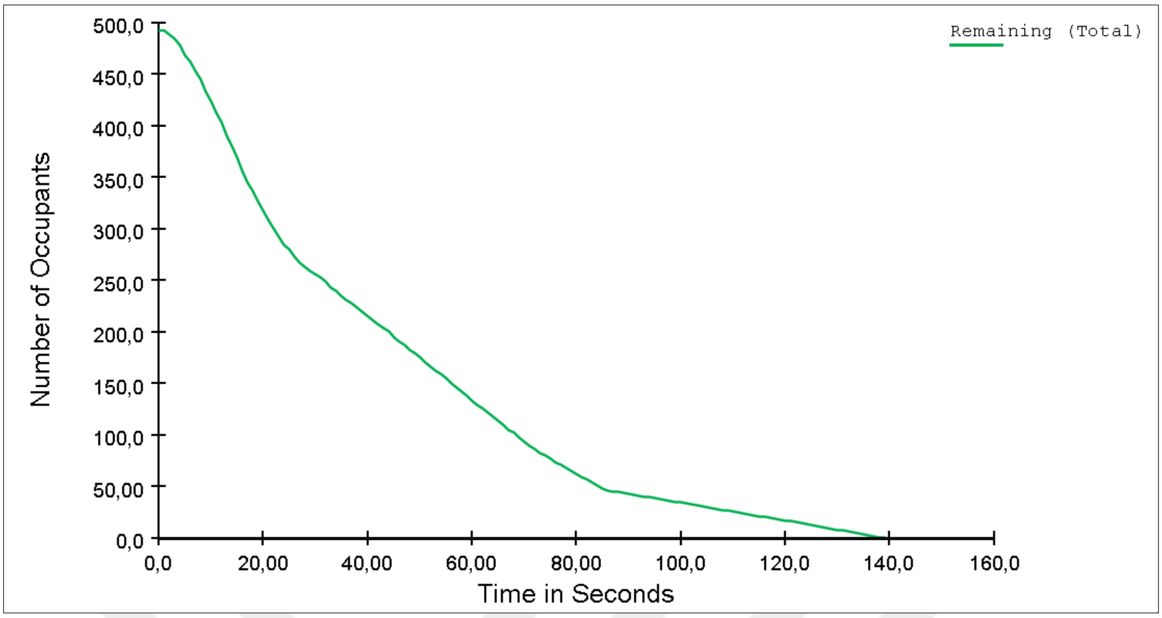


Figure 5.29. Total evacuation time for all occupants

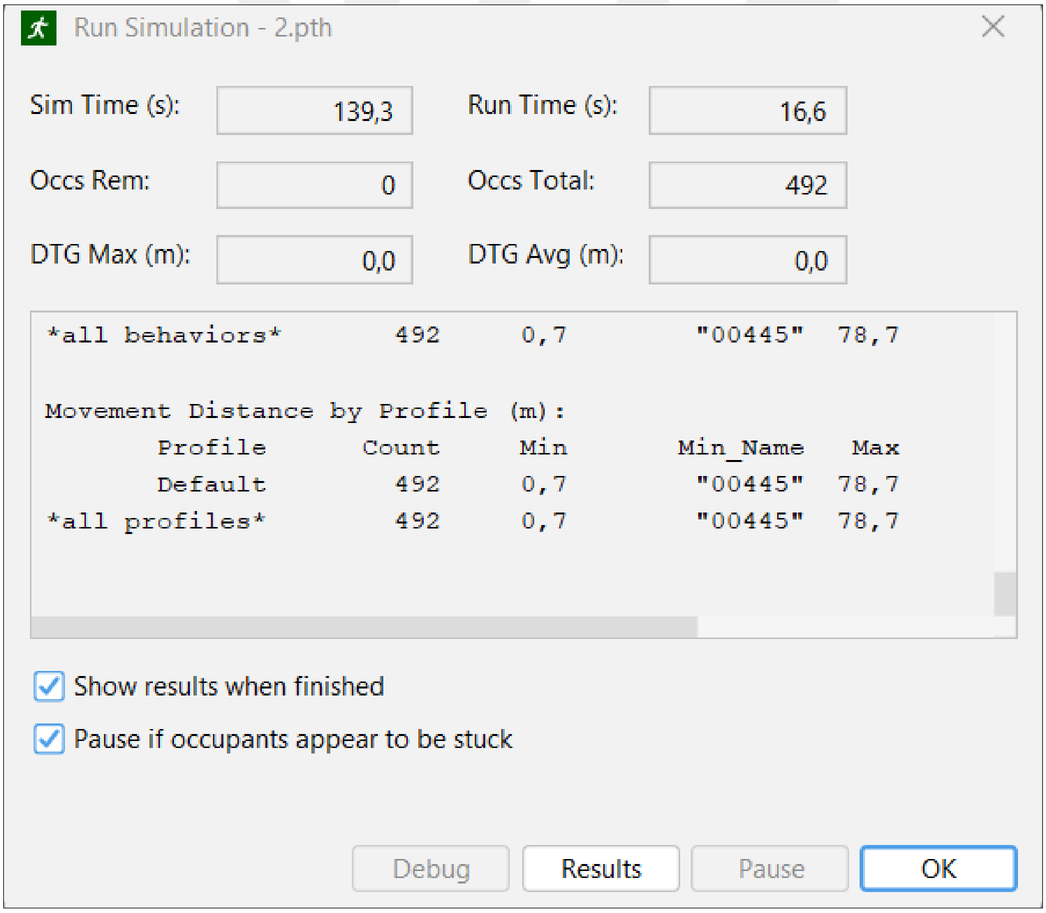


Figure 5.30. Simulation time of the case study

To show the number of occupants in a building over time, a time-dependent graph was created (Figure 5.31). The complete evacuation procedure is divided into three sections in this graph. It displays 25, 90, and 139 seconds since the evacuation began. Figure 5.32 shows how the occupant flow rate has changed over time.

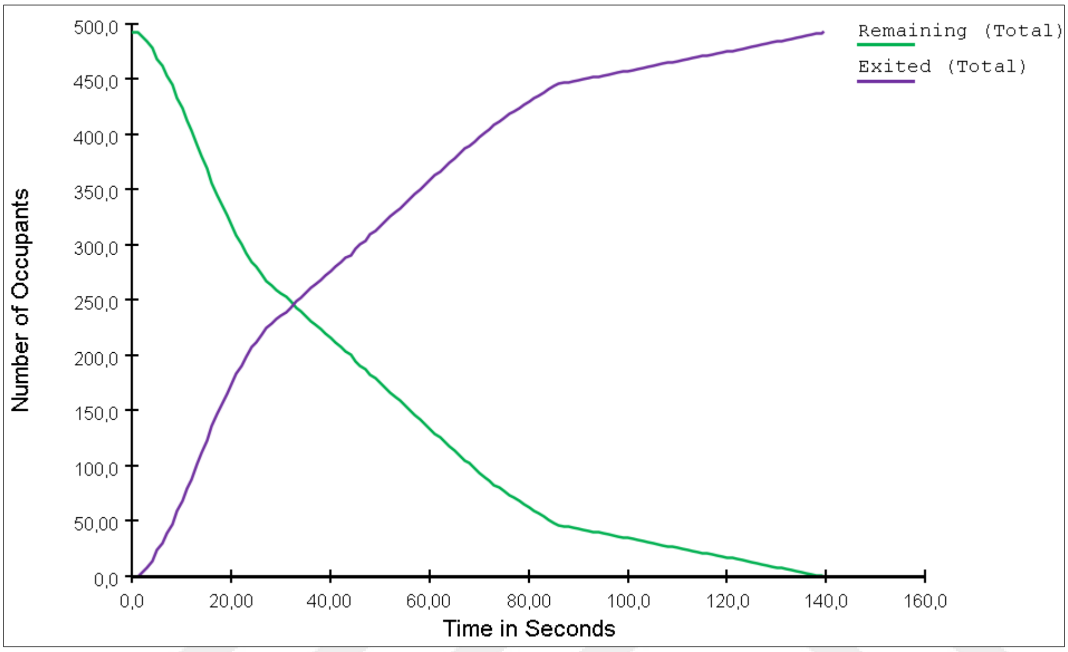


Figure 5.31. The change in the number of evacuees over time

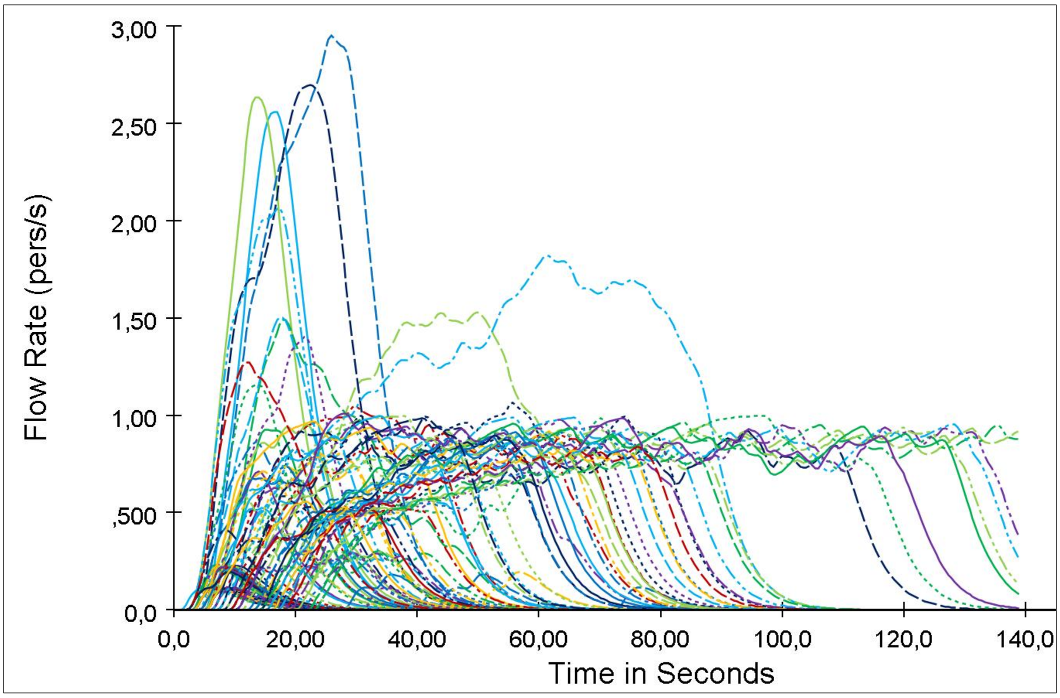
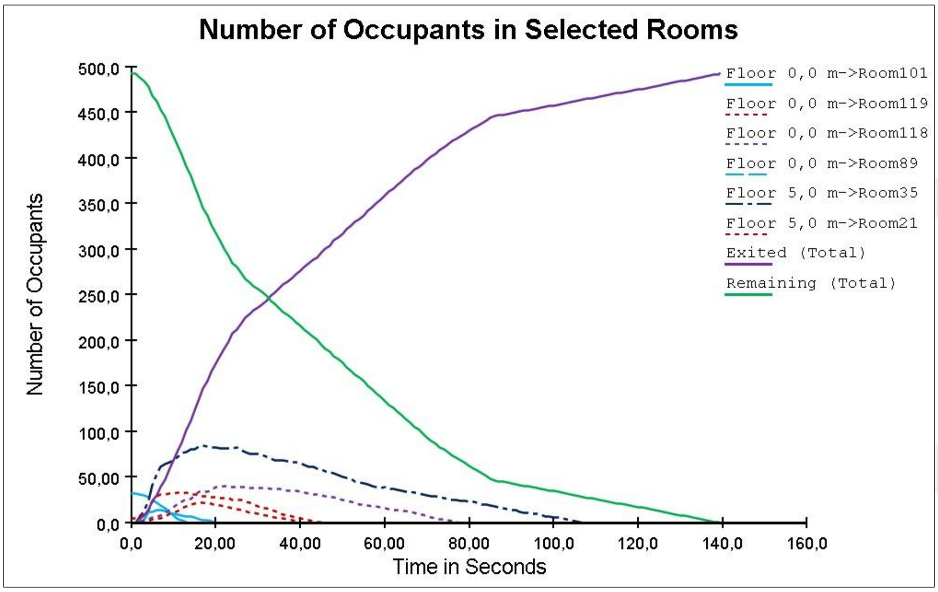
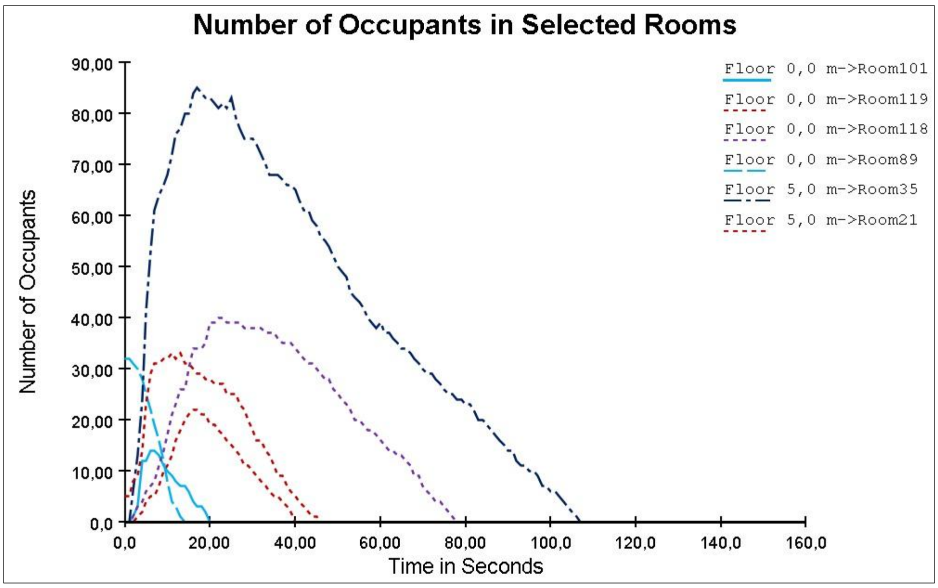


Figure 5.32. The change in occupant flow rate over time

To show the change in the number of occupants in the corridors over time, a time-dependent graph was created (Figure 5.33). Floors numbered 89, 101, 118, and 119 are ground floor corridors; rooms numbered 21 and 35 are first floor corridors. The graph indicates that the density increased at the beginning of the evacuation as occupants exited the rooms into the corridors. Toward the end of the evacuation, it is interpreted that occupants moved from the corridors to the fire escapes and exits.



(a)



(b)

Figure 5.33.a,b. The change in the number of evacuees over time in the corridors

6. CONCLUSION

Due to the rapid population growth on a global scale, the demand for consumption is increasing, and as a result, the need for production is also increasing. Consequently, large-scale production areas such as industrial buildings are becoming increasingly functional, and their numbers are growing day by day. As technology advances to meet consumption demands, industrialization mechanisms are increasing; however, this has also led to a noticeable increase in the number of industrial accidents. As a result of these accidents, there has been a year-on-year increase in industrial fires.

With the increasing need for industrial production, Organized Industrial Zones (OIZs) have gained significance in terms of both planning and sustainability. These zones help reduce the pressure of unplanned urban sprawl on city centers by directing industrial development to designated areas. Well-planned OIZs ensure more efficient infrastructure use, lower environmental impact, and safer industrial environments. Additionally, by separating industrial functions from residential and commercial areas, they contribute to a more balanced and healthy urban structure. In this context, the proper planning and fire safety design of OIZs play a critical role in minimizing risks associated with industrial growth.

Fire safety measures are of great importance in industrial buildings due to the presence of flammable and explosive materials. The measures taken in these facilities, taking into account the possibility of fire, aim to minimize the risk. However, if there is no timely intervention, people may lose their lives and significant material damage may occur as a result of fire.

A number of measures must be taken from the design and construction stage onwards, depending on the intended use of industrial buildings. These measures are categorized as passive and active measures. The following are taken into account in the architectural design and implementation of industrial buildings for fire safety purposes:

• Compartmentalization using fire-resistant wall, ceiling, and flooring systems,
• Planning of fire escape routes and protection of emergency escape routes with fire and smoke-resistant materials,
• Fire-resistant building elements and materials used in the structure, as well as properties that prevent the spread of fire,
• Use of fire-resistant roof systems and façade materials to ensure that roof ventilation units and insulation materials are fire-resistant,
• Use of fire-resistant doors and entry/exit control systems to minimize smoke/toxic gas transfer between production lines,
• Designing fire stop applications and void barriers suitable for industrial equipment by sealing pipe, cable, and duct penetrations with fire-resistant materials,
• Use of innovative materials and technologies,
• Protecting steel supports by coating them with intumescent (expanding) paints to prevent bending/collapse under high temperatures,
• Use of fire curtains to protect large openings from vertical smoke and flame passage,
• Separation of production and storage areas of industrial buildings with fire walls,
• Control of smoke movement and delaying fire spread,
• Integration of fire and smoke dampers into HVAC systems to prevent smoke spread in large-volume production areas,
• Performance-based design,
• Industrial buildings should be located in planned industrial zones with strong infrastructure, away from city centers,
• Measures should be taken to ensure that firefighting vehicles can reach the fire quickly, taking into account issues such as the positioning of firefighting vehicles around the building and their approach distance to the building.
• Establishment of periodic maintenance, inspection, and recording systems due to the need for continuous monitoring and documentation of complex industrial buildings,

such passive fire safety measures reduce risks in the event of a fire and ensure preparedness for any fire situation. In this context, the research analyzed passive measures that can be taken for fire safety from an architectural perspective during the design phase, providing unique and applicable results for industrial buildings. As a result, passive systems are among the primary measures taken to protect industrial buildings from fire. Properly considered passive fire safety measures during the design phase will reduce the need for active fire safety systems, which have a significant impact on building costs, and ensure that the building's fire safety is permanently maintained. Active and passive systems must work together in an integrated manner. It is a well-known fact that if passive measures are sufficient, the effectiveness of active measures will also increase.

In order to resolve and eliminate fire safety issues and risks, it is necessary to develop building-specific and performance-based approaches. There are two general approaches followed in the drafting of regulations. One is the prescriptive or normative approach, and the other is the performance-based approach. Within the framework of TRRFP regulations written using the prescriptive approach, the use of performance-based approaches, the development and revision of regulations in this context, and the creation of performance-based and user-focused fire safety measures specific to architectural projects, as well as the provision of appropriate evacuation conditions, are of great importance.

Escape routes are one of the most important design criteria in building design. Provisions on these issues are included in national and international legislation, and researchers have conducted numerous studies using computer simulation models based on performance. With the increasing popularity of performance-based design methods and the use of such tools by both designers and regulatory bodies, it will be possible to construct more efficient buildings, especially industrial buildings.

This research highlights the benefits of utilizing fire evacuation simulation tools. Scientific data were obtained for the model to be created by conducting escape analyses with simulation software support on the selected the case study. For this purpose, PATHFINDER' software, which is CAD-compatible, can evaluate user behavior and uses architectural data, was selected among the software that performs escape analysis mentioned in the introduction.

A printing service building to be built in Ankara was selected as a case study, and evacuation times were analyzed with the performance-based Pathfinder motion simulation. The overall simulated evacuation time acquired by running the software is 139.3 s (2.3 min). As a result, the building was evacuated safely. Evacuation programs provide guidance in determining hazardous areas that must be taken into account when calculating evacuation times and drawing up industrial building and evacuation plans.

The research's findings give guidance for architects and engineers working on passive fire safety measures in industrial buildings, as well as performance-based fire simulation systems. It also offers an alternative evacuation analysis method for researchers, ministries, professional groups, and authorities involved in fire safety engineering. Active systems, which are not covered in this study but are complementary to design and implementation, should be addressed in future studies. The studies and standards on this subject should be examined in detail and included in the literature. The subject will reach integrity with future research.

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