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Quantitative Risk Analysis of Fire Load and Combustible Materials in Office Workplaces in the United States.

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Abstract: *Fire safety in office workplaces is a major issue in the United States, as occupants are concentrated in dense and combustible materials, which increases the risk of fire. This research helps fill that gap in the quantitative measures testing the rate of fire load in the U.S. office environment. The goal is to determine the fire load through an analysis of the contributions of productivity of paper, plastics, and electronics, textiles, and chemicals, as well as an assessment of compliance with NFPA and OSHA standards. By using a quantitative risk analysis, the research combines fire load calculations with code-based checklists with case-based applications to identify where, for example, the high-risk areas for fire can be found - archives, server rooms, kitchenettes. Findings indicate that many offices have fire loads that exceeds recommended limits and poor housekeeping and clustered electronics add to office risks. The study makes the following conclusions: combining code compliance, digital recordkeeping, and the use of intelligent technologies that detect fires is a necessity. Broader implications are about promoting fire safety culture at work, engaging with policymakers, and offering support for proactive risk mitigation strategies.*

Key Words: Fire Load, Office Workplace Safety, Combustible Materials, NFPA Standards, Risk Assessment, United States

Inroduction

Fire safety is a major issue of concern in the built environment, especially in office buildings in the United States, where large populations and the presence of valuable properties lead to a situation of increased vulnerability (Campbell, 2013; Hall, 2014). The National Fire Protection Association (NFPA) has reported that thousands of fires take place in office properties in the United States each year, leading to property losses, business disruptions, injuries, and deaths (Campbell, 2013; NFPA, 2022). Fire load, which is described as the cumulative potential heat energy discharged by combustible products in the specified region, in megajoules per square meter (MJ/m 2), is one of the main factors determining fire severity (Khorasani, Garlock, and Gardoni, 2014). Increased fire loads make fires more intense and long-lasting, making it a challenge when attempting to suppress and evacuate people (Thauvoye, Zhao, Klein, and Fontana, 2008).

In spite of its significance, fire load assessment is often underestimated in facility workplaces because most organizations only consider code compliance, but not comprehensive risk assessment (Furness and Muckett, 2007; Sun and Luo, 2014). In office work environments, the amounts of combustible substances, such as paper records, upholstered furniture, electronic equipment, and plastic-based products, are usually high, and they increase fire loads to potentially dangerous levels (Hassanain, Al-Harogi, and Ibrahim, 2022). Moreover, the U.S. experience proves that not only property damage costs millions of dollars annually, but also operational disruptions and psychological effects cause the employees to experience a lasting impact of fire incidents (Hall, 2014; NFPA, 2022).

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NFPA has documented that most injuries in office fires are attributed to delayed evacuation, which is usually worsened by the lack of sufficient exits, blocked means of evacuation, or lack of preparedness by the occupants (Kuligowski & Hoskins, 2011). These results highlight the importance of the combined approach to safety, which involves structural fire protection and behavioral preparedness. Although international fire research has developed measures of quantifying fire load in diverse building types (Danzi, Fiorentini, and Marmo, 2021; Brzezińska and Bryant, 2020), not many studies have contextualized these evaluations to the office setting in the United States. This gap is addressed in the present paper by applying a quantitative analysis of the risk of fire load at American workplaces aimed at producing actionable information on facilities managers, policymakers, and safety engineers.

Objectives of the Study

The main goal of this study is to perform a quantitative fames calculation of the fire loads in offices in the United States by analyzing the role played by combustible materials, materials that cause the ignition of fires, housekeeping, and the level of correction of safety standards established by the NFPA and OSH, from the office, paying special attention to areas with high risk such as archives, servers, kitchens, etc. A secondary objective for the project is the development and recommendation of effective risk reduction strategies such as digital recordkeeping, better housekeeping practices, improved fire detection technologies, and the better enforcement of adherence to safety codes that can provide practical guidance for facilities managers, safety engineers, and policymakers to mitigate the fire hazards at work and improve the overall occupational safety.

Literature Review

Fire load is the total amount of the potential energy that is released in the course of a fire event, which is normally measured in megajoules per square meter (MJ/m2). The central point of fire risk assessment is this measure because it offers a quantitative foundation of the severity and the spread potential of fires (Khorasani, Garlock, and Gardoni, 2014). The literature on the subject invariably states that the high fire loads in office buildings, which are mainly caused by the accumulation of paper, plastic materials, and electronic devices, play a crucial role in the severity and length of fire (Thauvoye, Zhao, Klein, and Fontana, 2008; Sun and Luo, 2014).

In the US, there are codes and standards established by the National Fire Protection Association (NFPA, 2022) and the Occupational Safety and Health Administration (OSHA, 2021) with the aim of reducing the occurrence of fire incidents in the workplace. NFPA standards include NFPA 10 (portable extinguishers), NFPA 13 (sprinkler systems), NFPA 70 (electrical codes), and NFPA 101 (life safety code), which are the most general requirements towards office fire prevention and suppression (NFPA, 2018, 2022). These standards are supplemented by OSHA, which also focuses on the training of employees, warning them about hazards, and safety evacuation plans (OSHA, 2021). In spite of these frameworks, office fire incidents are still present in the U.S., and this proves that efforts to enforce rules and maintain compliance and safety culture in organizations are still persistent (Hall, 2014).

Past research mentions electricity wiring flaws, a circuit overload, malfunctioning home appliances, and inadequate storage of combustibles as common causes of office fires (Campbell, 2013; Hassanain, Al-Harogi, and Ibrahim, 2022). Risks are further enhanced by human factors such as negligence, poor housekeeping, and lack of awareness. According to Kuligowski and Hoskins (2011), delay in evacuations or misuse of fire doors by occupants is the factor that usually determines the outcomes of occupants in high-rise office fire disasters. These results indicate that the question of fire safety cannot be resolved only on a technical level; behavioral and cultural aspects should be included.

Although the international literature, especially in Europe and Asia, has already created fire load assessment methods, quantitative analyses specifically related to the U.S. workplace are scarce (Brzezińska and Bryant, 2020; Danzi, Fiorentini, and Marmo, 2021). The examples of the high-rise fire in Chicago in 2003 that occurred as a result of improper storage management and lack of fire-fighting sprinklers can help illustrate the implications of not taking fire load into account. Comparative studies also suggest that the U.S. workplaces, which typically feature voluminous paper files, expansive IT systems, and open design plans, can have a distinctive fire load profile as compared to those abroad (Koutscomarkos, Rush, Jomaas, and Law, 2021).

Combined, the literature indicates that an integrative approach, such as NFPA and OSHA code compliance, active employee training, and the implementation of computer-based fire management solutions, can provide the most promising route towards minimizing the occurrence of fire hazards in the workplace in the U.S. setting. The present paper will help address the research gap by implementing calculations of fire loads in accordance with the NFPA standard in office work-related places in the U.S. and, as a result, align the global methodology with the domestic safety standards.

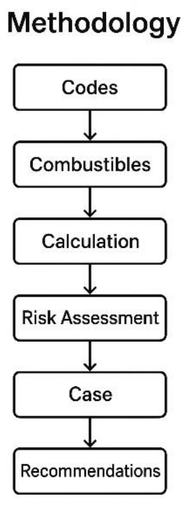
Research Methodology

Research Design

This paper uses a quantitative risk analysis approach to assess how the use of combustible materials contributes to the level of fire load present in the U.S. office workplaces. Design constitutes a combination of three elements: (1) a review of fire safety codes and standards in the U.S, (2) a calculation of fire load using combustible materials, and (3) a case-based evaluation of risk at work.

Figure 1

Research methodology flowchart illustrating the process from code review to recommendations



This interdisciplinary methodology makes it possible to guarantee both rigor and applicability.

Data Sources

It is based on the approach aimed at utilizing four types of data:

Regulatory Frameworks: There were fire safety codes and standards offered by the National Fire Safety Association (NFPA) and the Occupational Safety and Health Administration (OSHA). Key standards include:

NFPA 10: Standard of Portable Fire Extinguishers (2018).

NFPA 13: Standard of the Installation of Sprinkler Systems (2019).

NFPA 70: National electrical code (1981)

NFPA 72: National Fire Alarm and Signaling Code (2019).

NFPA 101: Life Safety Code (2021)

General Industry Rules on OSHA Fire Safety Standards (2021).

Statistics: The Fire Loss in the United States reports (20182022) by NFPA, which contains the ignition causes, human and property damage statistics.

Academic Literature: Academic investigations into the evaluation of the fire load and workplace safety (e.g., Khorasani, Garlock, and Gardoni, 2014; Thauvoye, Zhao, Klein, and Fontana, 2008; Danzi, Fiorentini, and Marmo, 2021).

Case Evidence: Automobile accidents in the U.S., office fire, e.g., the Chicago high-rise fire (2003), and global standards (Hassanain, Al-Harogi, and Ibrahim, 2022).

Fire Load Calculation

The formula that is widely recognized in the field of fire load is applied in the study (Khorasani et al., 2014):

$$Q=\frac{\sum(M_i \times H_i)}{A}$$

Where:

Q = fire load (MJ/m²)

M i = the mass of combustible material i (kg).

H i (in MJ /kg) = the heat of combustion of material i.

A = floor area (m²).

The combination of combustible types that were taken into account was the following:

Paper products (files, records, packaging)

Plastics (furniture, partitions, electronics casings)

Wood and textile (desks, furniture, upholstery)

Electronic gadgets (computers, servers, printers)

Toxic office materials (toners, solvents, cleaning materials).

Engineering sources provided the standard values of heat of combustion (i.e. paper 16 MJ/kg, plastics 2535 MJ/kg), which were used accordingly (Thauvoye et al., 2008). The modeled sample calculations were based on a wide range of office floor areas, 500-2,000 m 2.

Table 1: Fire load contributions of common combustible materials in U.S. office workplaces.

Combustible Material	Mass (kg)	Heat of Combustion (MJ/kg)	Fire Load Contribution (MJ)	Fire Load Density (MJ/m²)
Paper Products	200	16	3,200	6.40
Plastics	150	30	4,500	9.00
Wood/Textiles	100	18	1,800	3.60
Electronics	120	22	2,640	5.28
Cleaning Chemicals	50	25	1,250	2.50
Total	—	—	13,390	26.78

Risk Assessment Framework

A code-d checklist was modified to assess the adherence to the U.S. standards, adapted by Hassanain et al. (2022). It separates fire precaution into six categories:

Exits - Sufficiency, width signage and access.

Fire Protection Systems- sprinklers, detectors, alarms, extinguishers.

Housekeeping Measures - storage and disposal of combustibles.

Electrical Installations- use of extension cords, marking of electrical rooms.

Miscellaneous Measures- hydrant access, evacuation plans, visible address.

Hazardous Materials- sorting and classification of chemicals.

All measures were verified with standards of NFPA and OSHA. The weaknesses were considered as high-risk factors.

Case Application

It was used to apply to hypothetic office layouts that fall under Business (B) occupancies defined in NFPA 101 (2021). The high- risk areas identified by simulations were:

Paper rooms (high paper loads), Archives, and storage rooms.

IT /server rooms (electronics and plastics)

Appliances and chemicals (kitchenettes).

A sensitivity analysis was used to consider the effects of material replacements (e.g., flame-retardant furniture, computer-based record-keeping) and adherence to fire codes on total fire load.

Limitations

There are a number of constraints on this methodology:

Material Data: Existing heat of combustion values are not necessarily representative of the variety of modern office materials (e.g., composites, lithium-ion batteries).

Weaknesses in Enforcement: NFPA and OSHA have their own strong frameworks, yet real enforcement is quite different in different working environments.

Empirical Boundaries: Since the research involved the use of secondary data and modeling layouts as opposed to an on-site survey, findings are an indicator of the results but not actual measurements.

Combustible Contents and Fire Load of Office Workplaces in the U.S.

Widely used combustible substances in the U.S. offices comprise:

Paper products: books, files, documents and cardboard.

Electronic devices: computers, printers, copiers and shredders.

Furniture and furnishing: desks, chairs, upholstery, and plastic partitions.

Cleaning solvents, toner, cleaning agents and office machines.

These are inflammable substances that add a lot of values to fire loads. The thermal energy of combusting paper was approximately 16 MJ/kg and the plastics may be 25 to 35 MJ/kg.

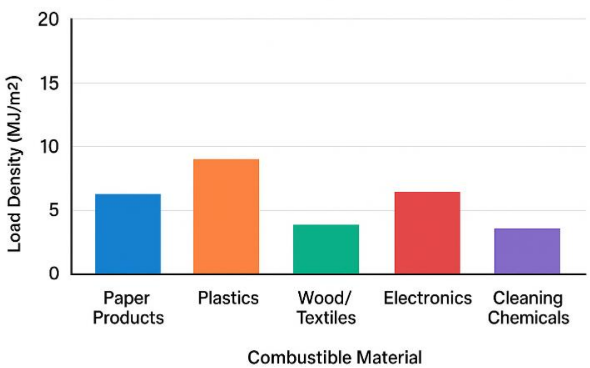


Figure 1: Fire load density distribution by combustible material, showing plastics as the highest contributor.

Companies with large archives in offices can have a fire load that is above the NFPA safety measure. Sources of ignition, such as faulty wiring, faulty equipment, or extremely careless disposal of smoking material, aggravate these risks. According to quantitative analyses, storage rooms, server rooms and kitchenettes tend to help record the highest fire load values. Besides, office designs such as open-space areas reveal combustible substances that allows more rapid spread of fire as compared to compartmentalized offices. Flooring, plastics, and artificial upholstering material contribute so much heat energy when burning. These architectural choices accidentally add fire hazards in the U.S. where shared workplace designs are gaining popularity. There is also the unexploited e-waste accumulation, such as unused computers, printers, and other e-waste, which often contain lithium-ion batteries and other corrosive materials, posing a higher risk of fire. This should be coupled with quantitative calculations of fire loads to give the entire picture of the magnitude of combustible risk in the dynamic nature of the workplace.

Risk Assessment Findings

The risk evaluation revealed that the U.S. offices have been inclined to surpass the recommended fire load limits due to the huge quantities of paper storage and heavy utilization of electronics. High-risk zones include:

Large flammable storage storage rooms in the archives and files.

Electronic assets which are clustered in IT server rooms.

Kitchenettes that are heated and have cleaning materials which are combustible.

Poor housekeeping, including failure to dispose of waste papers and poor storage of chemicals, were common problems. NFPA reports cite electrical malfunction or cooking equipment as prevalent causes of fire in the office in the U.S., and that the high fire loads compound such fires. These findings emphasize how the increasing intensity of compliance control and active measures to reduce fire loads are so needed. Moreover, comparative analysis revealed that the offices situated in the urban centers with a higher concentration of electronic devices and digital infrastructure have significantly higher fire load values in comparison with the suburban offices. NFPA case studies further exhibited that offices with inadequate fire drills, or those whose emergency response plans were deemed obsolete, had a low evacuation rate, and these collectively led to an increase in the number of injuries. It means that fire load cannot be a mere object of physical property, but one that is closely related to organizational culture and safety preparedness. Another result of the evaluation was that many of the offices lacked the inspection records, which weakened the work of the fire safety devices and created unnoticed loopholes.

Discussion

The findings highlight the importance of considering fire load as being one of the most essential elements of the fire protection planning within the workplace. Huge loads of fire do not just intensify fire, but also erode the evacuation and suppression of fire. Passive (fire-resistant walls, doors, and ceilings) and active (sprinklers, alarms, and extinguishers) fire protection systems of the U.S. scenario should be combined. A behavior-based safety culture should also be developed where the workers understand the hazards of improper storage, overloading circuits, and neglect of safety concerns. The digital documentation, regular inspection of the electrical systems, and maintaining good housekeeping are the cost-effective strategies in fire load reduction. Early warning and response time may also be improved with smart technologies created by policymakers and safety engineers (i.e., IoT-based fire detection systems). Economic factors, along with structural and behavioral factors, are also elements of fire safety that are very important. Fewer resources are generally available to smaller companies to install the newest sprinkler systems and conduct frequent safety audits, which puts their employees at higher risk. Insurance incentives could be used to encourage compliance and investment in fire safe materials. In addition, the creation of building information modeling (BIM) and the digital twin possibilities can reproduce the fire circumstances that could allow organizations to predict and mitigate the high-risk spaces in advance. The workplaces in the United States should go beyond being a minimum compliance strategy and adopt a proactive culture of fire safety and integrate it within the comprehensive occupational health and safety strategies.

Recommendations and Conclusions.

This research paper summarizes the importance of fire load and combustible materials in defining the magnitude of fire risk in the U.S. office workplaces. Through the quantitative analysis, it is proven that basic house office combustibles, together with subpar housekeeping and electrical hazards, present a high fire load. In order to overcome these risks, it is proposed to provide the following recommendations:

Lessen paper addiction with electronic storage.

Periodically perform fire load testing on the basis of NFPA guidelines.

Enhance housekeeping measures to minimize combustible build up.

Strict adherence to fire safety codes of NFPA and OSHA.

Install intelligent fire detection and surveillance equipment.

Through the above measures, the U.S. organizations will be able to minimize the fire hazards in the workplace, protect the lives of employees as well, and secure important business resources. The combination of the behavior-based methods of safety and the fire load quantitative analysis is a guarantee that both the physical and human factors are considered in fire risk mitigation strategies. Further research should reflect on office-specific arrangements of industry, such as technology companies, where electronic density is higher than in legal companies with high paper archives, to build customized fire safety systems. Besides this, the policy makers would be interested in considering implementing the use of digital fire load reporting in the process of conducting annual safety audits to introduce transparency and accountability. Lastly, the findings lead to the fact that it is not merely a regulatory or a moral obligation to control the fire load in order to be able to save lives, safeguard businesses, and offer stability to the U.S. workplace sector.

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