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# Adequacy and Performance of Fire Protection Systems and Means of Escape in the Terminal Buildings of Kenya's International Airports

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## Abstract

**Purpose:** Fire outbreaks are global hazard with potential to cause injuries, loss of life and damage to properties. To mitigate against these fires, fire safety of the building should be considered during the design and construction phases of a building, supported by effective implementation of fire safety management including provision of adequate serviceable and reliable fire protection and detection systems to enhance safety of buildings against unforeseen fires in complex occupancies like airports. This study assessed adequacy of fire protection systems and egress at international airports' terminal buildings in Kenya.

**Materials and Methods:** The study adopted a cross-sectional descriptive survey, involving eight (8) International airports in Kenya. It involved use of checklists and photography to record observations in the workplace. A tape measure was used to take linear measurements of emergency exit door width, mounted portable fire extinguisher heights on walls. The collected data were summarized, analyzed and presented in tables.

**Findings:** The study revealed that most fire protection systems and means of escape at Kenyan international airports were inadequate and poorly maintained. 19.7% of portable fire extinguishers lacked safety pins, 58.4% were uninspected or were overdue for inspection, 53.8% were obstructed, 18.4% had their gauge on red zone, 45.6% were mounted more than 60cm on the walls, 12.0% were exposed to adverse weather and none had undergone hydrostatic testing. 56.7% and 53.3% of hose reels were dry and lacked opening knobs respectively, while 58.6% were obstructed. Fire hydrants were also deficient, with 61.2% of them had inadequate pressure, 55.8% lacked hydrant covers, 61.2% were dry while 61.5% were obstructed. Escape routes were equally compromised. Approximately 61.1% of the emergency exits were obstructed, 71.1% of the assessed workplace lacked alternative means of escape. About 87.5% of the assessed workplace lacked sprinkler systems.

**Unique Contribution to Theory, Practice and Policy:** This study supports risk and safety management theories by showing that adequacy of fire protection systems and means of escape is not just a technical requirement but also a behavioral and organizational factor in enhancing airport safety. Further, it highlights the need for airport operators to prioritize regular inspection and maintenance of fire protection systems to ensure reliability.

**Keyword**: *Adequacy, Fire Protection Systems, Means of Escape, International Airports, Kenya*

***K32:*** *Energy, Environmental, Health and Safety Laws*

## INTRODUCTION

Fire safety involves design, construction, and management of occupancies to prevent fire outbreaks and minimize their consequences. It includes provision of fire protection systems, adequate and unobstructed means of escape, systematic maintenance, and promotion of fire safety awareness among occupants (Onyekwere, 2022; Kodur *et al.*, 2020). In high-risk facilities like airports which are characterized by high occupant density, complex layouts, fuel-related hazards, and continuous operations; effective fire safety management is critical to safeguarding lives, properties and maintaining operational continuity (GOK-FRRR, 2007; Yildirim & Demirel, 2019). Fire incidents can result in fatalities, business disruption, data loss, reputational damage, and long-term operational and financial consequences (Kodur *et al.*, 2020).

Kenya's civil aviation sector comprises international and domestic airports, managed by Kenya Airports Authority and regulated by Kenya Civil Aviation Authority. International airports in Kenya handle substantial and growing passenger volumes, placing pressure on terminal infrastructure, emergency response systems, and Airport Rescue and Firefighting Service (ARFFS), thereby increasing both the likelihood and potential severity of fire emergencies.

A study by Wambugu *et al.* (2016) at Jomo Kenyatta International Airport revealed deficiencies in preventive measures, maintenance practices, coordination, and response capability. These findings underscore the need to move beyond mere regulatory compliance toward a performance-based approach that emphasizes how fire protection systems and emergency services actually perform under real emergency conditions.

Fire protection systems are integral to airport infrastructure and must function reliably during emergencies. Their effectiveness depends not only on design and installation but also on continuous inspection, testing, maintenance, and competent personnel (Kodur *et al.*, 2020; Alao *et al.*, 2021). A performance-based approach prioritizes operational readiness, system reliability, response effectiveness, and measurable safety outcomes, supported by preventive and corrective maintenance programs and personnel training.

This study assessed adequacy and reliability of fire protection systems, the adequacy of means of escape, the effectiveness of maintenance practices, and determined the overall performance-based effectiveness of fire safety management in Kenyan international airports. Focusing on these aspects is essential to reducing fire risk, enhancing emergency response, and ensuring operational resilience and continuity.

### Statement of the Problem

The Kenyan Fire Risk Reduction Rules (FRRR) and the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) establish prescriptive minimum requirements for fire protection systems and means of escape at airports, with emphasis on compliance with defined design, installation, inspection, and maintenance standards. While these frameworks provide a necessary regulatory baseline, they do not explicitly require demonstration of fire safety performance under realistic fire development and evacuation conditions (Society of Fire Protection Engineers [SFPE], 2019).

Globally, airport fire safety practice has increasingly adopted performance-based fire engineering (PBFE) approaches to evaluate system effectiveness in complex, high-occupancy environments such as airports (Purser, 2020). In contrast, evidence from Kenya indicates persistent deficiencies in firefighting capability, emergency preparedness, evacuation provisions, and inadequate aircraft rescue and firefighting service (ARFFS) staffing at

international airports, despite formal regulatory compliance (Wambugu *et al.*, 2016; International Air Transport Association [IATA], 2023).

Notably, no empirical study has evaluated whether fire protection systems and means of escape at Kenyan international airports perform adequately under credible fire and evacuation scenarios, thereby limiting objective verification of system adequacy and resilience which in constrains effective fire safety management and regulatory advancement. It is within this context that this study was undertaken to determine the adequacy and performance of fire protection systems and means of escape at Kenya's international airports, and to provide evidence-based insights to strengthen fire safety management within the aviation sector.

### Research Gaps

Although fire protection systems and means of escape are essential for life safety (Kodur *et al*., 2020), most existing literature remains prescriptive or theoretical, with limited empirical evaluation of system performance under real operational conditions. Complex facilities such as airport terminals with high passenger throughput, mixed-use occupancies, and time-critical operations pose challenges which prescriptive approaches alone may not address (Lehna *et al*., 2024; İşeri & Yaşar, 2025). Globally, performance-based fire engineering (PBFE) has been adopted to assess whether fire protection and evacuation systems achieve intended safety objectives under realistic fire scenarios (Purser, 2020). While PBFE has been applied in complex infrastructure such as airports, empirical studies validating these approaches in operational airport environments are scarce. In Kenya, studies at Jomo Kenyatta International Airport and Wilson Airport have examined emergency preparedness but did not assess the adequacy, reliability, or operational performance of fire detection, suppression, or evacuation systems (Wambugu *et al.*, 2016; Nambuya, 2021). Consequently, there is no empirical, performance-based evidence demonstrating whether airport fire protection systems and means of escape in Kenya meet their intended operational and life-safety objectives under realistic fire conditions. This knowledge gap limits objective verification of system effectiveness and underscores the need for performance-based evaluation to strengthen fire safety management and inform regulatory and operational decision-making.

## MATERIALS AND METHODS

### Study Design

The study employed a cross-sectional descriptive design across all eight (8) international airports in Kenya, using a census approach. Ethical approval was obtained from the Jomo Kenyatta University of Agriculture and Technology Institutional Scientific and Ethics Review Committee, and written authorization was granted by the Kenya Airports Authority. Primary data collection involved taking linear measurements of emergency exit door widths and portable fire extinguisher heights using a tape measure, as well as the assessment of the adequacy and compliance of emergency signage, emergency exits, fire hydrants, and fire protection systems using checklists and photographic documentation. All collected data were treated with strict confidentiality to ensure data protection and privacy. Collected data were subsequently summarized, analyzed, and presented in tables for descriptive interpretation.

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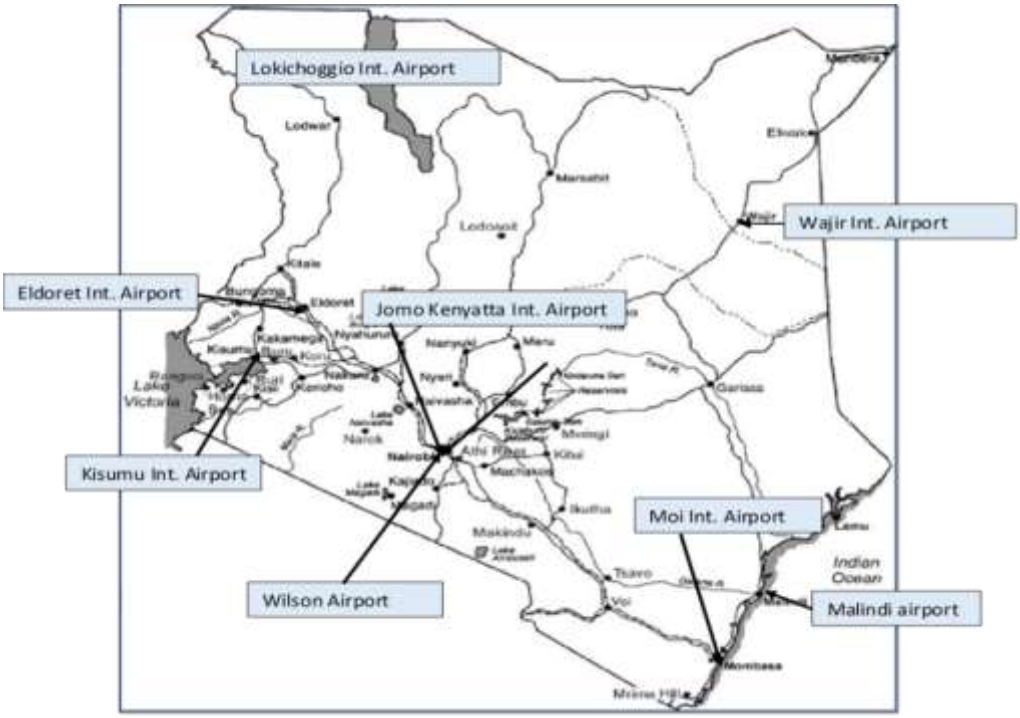


*Figure 1: Map Showing Study Areas*

*Source: https://www.google.com/*

**FINDINGS**

**Table 1: Fire Protection System**

| Fire Protection | No. Assessed | % Compliance |
|---|---|---|
| 1. Portable fire ext. with safety pins | 836 | 80.3% |
| . Portable fire ext. with updated inspection sticker | 836 | 41.6% |
| 3. Portable fire ext. not obstructed | 836 | 46.2% |
| 4. Portable fire ext. with gauge on green portion | 836 | 84.7% |
| 5. Portable fire ext. mounted above 60cm on the wall | 836 | 45.6% |
| 6. Portable fire ext. protected against adverse wx | 836 | 88.0% |
| 7. Right selected portable ext. for fire load | 836 | 88.0% |
| 8. Portable fire ext. hydro testing | 836 | 0.00% |
| 9. Hose reel charged with water | 210 | 43.3% |
| 10. Hose reel not obstructed | 210 | 41.4% |
| 11. Hose reel with opening knob | 210 | 46.7% |
| 12. Fire hydrant with sufficient pressure | 52 | 30.8% |
| 13. Fire hydrant with hydrant cover | 52 | 44.2% |
| 14. Fire hydrants with water | 52 | 30.8% |
| 15. Fire hydrant not obstructed | 52 | 38.5% |
| 16. Emergency Exit not obstructed | 90 | 38.9% |
| 17. Width of Emergency Exit door ≥ 90cm | 90 | 68.9% |
| 18. Unobstructed Fire Assembly point | 54 | 72.2% |
| 19. Emergency door opening direction of egress | 90 | 71.1% |
| 20. Availability of serviceable automatic sprinkler | 8 | 12.5% |
| 21. Alternative means of escape provided | 83 | 28.9% |
| **Aggregate Mean of adequacy** | | **49.6%** |

**Portable Fire Extinguishers**

From Table 1, a total of 836 portable fire extinguishers were assessed. Of these, 80.3% had safety pins intact, 84.7% had gauges on the green zone, 88.0% were adequately protected from adverse weather conditions, 88.0% were appropriately selected based on anticipated fire load (i.e. class of fire expected in the occupancy, indicating reasonable compliance. However, despite the, major gaps were observed. Notably, none of the portable fire extinguisher had undergone hydrostatic testing, a procedure required every five years to ensure the structural integrity of the cylinders.

Additionally, 45.6% of them were mounted above 60cm from the floor though the requirement does not specify maximum mounting height. Furthermore, 53.8% were obstructed and 58.4% had not been inspected or were overdue for inspection.

According to Government of Kenya Fire Risk Reduction Rules [GOK-FRRR] (2007), portable fire extinguishers should be mounted at an easily accessible height of not less than 60cm from the floor, inspected and tested by a competent person at least once in annually, and subjected to hydraulic pressure testing at least once every five years. Based on these requirements, most of the assessed firefighting appliance were not compliant with the law.

These findings align with previous studies. Omunagbe and Kaseem (2023) concluded that inspection and maintenance of fire protection systems significantly influence the performance of fire safety management. Their study emphasized that enhancing the performance of these systems, along with providing adequate training for occupants, could minimize fire occurrences within the terminal buildings. Similarly, Kebut (2021) concluded that portable extinguishers act as the first line of defense against early-stage fires and that improper mounting in inaccessible heights affected implementation of fire risk reduction rules.

Lehna *et al*. (2024) further reported that scheduled maintenance and testing of fire protection system plays an important role in ensuring building's fire safety, highlighting the need for consistent implementation to assure their availability and reliability.

**Emergency Exits**

From Tables 1, a total of 90 emergency exits were assessed. Of these, 61.1% were obstructed (under lock and chain), 31.1% had a width less than 90cm, 28.9% of them opened inwards, and 71.1% of them lacked an alternative means of escape. According to GOK-FRRR (2007), emergency exits should be of at least 90cm wide, unobstructed and located in a manner to lead occupants to safer haven. Based on these requirements, the results are an indicator that means of escape is not compliant with the legislation, thereby posing a significant threat to occupants' safety during emergency.

These findings were in agreement with previous studies. Jasztal *et al.* (2022) concluded that emergency exits are best used during evacuation when they are unobstructed hence help in achievement of fire safety if integrated into a comprehensive fire safety management program. Similarly, Omunagbe and Kaseem (2023), observed that restricting or locking emergency exits as a security measure creates significant evacuation challenges by trapping occupants in dead-end conditions, thereby increasing occupants' risk during fire incidents.

**Fire Hydrants, Hose Reels and Sprinkler System**

From Tables 1, the assessment revealed that 56.7% of hose reels were dry and 58.6% were obstructed Likewise, 69.2% of the fire hydrants assessed were dry, and 61.5% were. obstructed, 69.2% of them had low water pressure while 55.8% had no covers. Additionally, 37.5% of the assessed airports, did not have fire hydrants installed. Although Legislation (GOK-FRRR,

2007) does not prescribe specific hydrant pressure values, it simply states that fire protection systems must maintain a pressure capable to raise water to the highest point of the workplace in the event of fire outbreak. The same legislation requires occupier to provide a dedicated water storage facility of at least 10,000L capacity, which must be kept full at all times for emergency use. These results are indicators to non-compliance with this legislation regarding provision of sufficient emergency water supply at the airport for expeditious replenishment.

According to (International Civil Aviation Organization [ICAO], Annex 14 volume 1, 2022), airport operators must provide supplementary water supplies at the airport for expeditious replenishment of foam tenders to ensure continuous application of the media and maintenance of survival conditions. With regards to sprinkler system, only 37.5% of the assessed airports had sprinkler system installed in selected floors and of these, only 33.3% had serviceable sprinkler system. According to National Building Code (2022), building exceeding 30m in height should have sprinkler system installed in them.

These findings were in agreement with previous studies. Lee *et al.* (2020) emphasized that a supplementary water supply for firefighting is essential for effective response and that its insufficiency posed additional threat to life. Kaseem *et al.* (2021) concluded that violation of fire safety regulations affected fire safety management in a building. Similarly, Pavithra and Perumal (2022) further concluded that a well-maintained sprinkler systems offer rapid response capabilities, to reducing the risk of extensive fire damage and providing valuable evacuation time in a building.

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

The findings of this study demonstrate persistent inadequacies in fire protection systems and means of escape within Kenyan international airports. The condition of portable fire extinguishers was particularly concerning, with significant portions failing to meet basic safety and maintenance requirements. Notably 19.7% of extinguishers lacked safety pins, 58.4% had not been inspected or were overdue for inspection, and 53.8% were obstructed. Additionally, 18.4% had their gauge readings in the red zone, indicating insufficient pressurization, while 45.6% were installed above the recommended mounting height of not more than 60 cm. Exposure to adverse weather was observed for 12.0% of extinguishers, and notably, none had undergone hydrostatic testing—an essential procedure for ensuring cylinder integrity.

Hose reel systems exhibited similarly critical shortcomings. A majority were found to be non-functional, with 56.7% reported as dry and 53.3% lacking operational opening knobs. Furthermore, 58.6% were obstructed. Fire hydrants, which form the backbone of structural firefighting operations, were also inadequate. The study found that 61.2% of fire hydrants had insufficient pressure, 55.8% lacked hydrant covers, 61.2% were dry, and 61.5% were obstructed. Such deficiencies severely compromise the ability of fire services to suppress fires effectively, particularly in high-risk aviation environments where response time and system performance are critical.

Means of escape were equally compromised. The assessment revealed that 61.1% of emergency exits were obstructed, undermining safe and rapid evacuation. Additionally, 28.9% of exits opened inwards directly violating established fire safety provisions requiring outward-opening mechanisms to prevent overcrowding and to minimize evacuation time during emergencies. While 68.9% of the exits assessed met or exceeded the recommended width of 90 cm, the lack of redundancy in escape design remained a major concern, with 71.1% of workplaces lacking alternative means of escape. The absence of sprinkler systems in 87.5% of

workplaces further heightens vulnerability, as sprinklers represent the most reliable first line of defence in controlling and suppressing fires before escalation.

The study revealed that fire protection systems at Kenyan international airports are undermined not only by technical deficiencies but also by regulatory limitations. The Fire Risk Reduction Rules, 2007 and the Occupational Safety and Health Act, 2007, regulation 33 (c) and regulation 70 (6c) respectively provide general requirements for fire safety but do not specify measurable performance criteria for critical installations, such as minimum hydrant pressure, or cylinder testing pressures (GOK-FRRR, 2007; Government of Kenya Occupational Safety and Health [GOK-OSHA], 2007). Similarly, ICAO Standards and Recommended Practices (SARPs) establish broad obligations for firefighting services and emergency planning but do not define specific, enforceable numeric performance criteria for fixed installations, leaving implementation largely to individual States (ICAO Annex 14 volume 1, 2022). These regulatory gaps hinder enforcement, allow inconsistent interpretation, and contribute to persistent deficiencies in system design, installation, maintenance, and operational performance. Consequently, the reliability and effectiveness of airport fire protection systems during emergencies are significantly compromised, posing heightened safety risks in a high-occupancy, complex operational environment.

**Recommendations**

Based on the above findings, the following recommendations are proposed to enhance fire safety management performance at International airports in Kenya:

i. Implementation of continuous inspection, maintenance, and functional testing of all fire protection systems including portable extinguishers, hydrants, hose reels, sprinklers, and emergency exits to ensure operational readiness and compliance with applicable standards and best practices.

ii. Provision of reliable, adequate, and uninterrupted emergency water supply to hydrants, hose reels, and sprinkler systems. This includes establishing redundancy in water storage, pump systems, and pressure monitoring to guarantee availability during emergencies.

iii. Installation and upgrade of fire protection systems in all occupied areas**,** ensuring adequate coverage of automatic sprinklers, hydrants, fire alarms, and portable extinguishers. Installations should meet recognized international standards and be appropriately mounted, protected from environmental exposure, and free from obstruction.

iv. Review of the Fire Risk Reduction Rules (2007) and relevant ICAO SARPs to establish measurable and enforceable standards such as minimum hydrant pressure requirements, mandatory hydrostatic testing intervals, and clear technical specifications for installation and maintenance of firefighting equipment. Updating these regulatory instruments will help align national practices with international fire safety requirements and enhance enforcement effectiveness.

v. Strengthening of training programs for airport employees and management on fire prevention, emergency response, and equipment handling including periodic drills, refresher courses, and evaluation of their competency. Adequate resources should be allocated to sustain training programs, including funding, trainers, and training materials, while scheduling training progressively to minimize operational disruption.

vi. Adopting a phased approach for implementation of the above recommendations, beginning with high-risk areas and critical systems. This approach should include

monitoring, evaluation, and adjustment based on performance outcomes, available resources, and emerging operational needs.

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**Conflicts of Interest Declaration.**

None

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