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Using Smart Fire Systems in Buildings in Afghanistan: A Case Study in Kabul

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ABSTRACT

Ensuring fire safety in residential buildings remains a critical component of sustainable urban development, particularly in developing countries. This paper evaluates the applicability and effectiveness of Intelligent Fire Protection Systems (IFPS) integrated with the Internet of Things (IoT) and smart automation in typical multi-story residential buildings in Kabul, Afghanistan. The study is based on the fire-risk situation of Kabul, where rapid informal urban expansion, high population density, unstable electrical grids and non-standard winter heating practices increase the probability of severe fire incidents. A three-dimensional Computational Fluid Dynamics (CFD) model was developed using Fire Dynamics Simulator (FDS) and visualized in Smokeview for a typical six-story residential building. Severe fire scenarios were considered, including apartment ignition and staircase ignition. The model was combined with evacuation assessment through Available Safe Evacuation Time (ASET) and Required Safe Evacuation Time (RSET). The results show that, under conventional conditions without automated systems, ASET is limited to 220-250 s for an apartment fire and decreases to 150-180 s for a staircase fire, while RSET for 150-200 occupants reaches 300-400 s. Therefore, the safety condition ASET > RSET is not satisfied. Intelligent sensors, automated alarm, localized smart sprinklers and smoke-exhaust integration reduce the maximum heat release rate by approximately 40-50% and increase ASET by about 100-150 s. The proposed low-power decentralized IFPS framework can improve early warning, evacuation safety and fire response under Kabul's power-supply and infrastructure constraints.

Keywords- Available Safe Evacuation Time (ASET), Computational Fluid Dynamics (CFD), Fire Dynamics Simulator (FDS), Intelligent Fire Protection Systems (IFPS), Internet of Things (IoT), Kabul, Required Safe Evacuation Time (RSET), Smoke view.

I. INTRODUCTION

Ensuring fire safety of buildings remains one of the key tasks of sustainable urban development. The relevance of this research topic is due to the high fire danger in Afghanistan and in its capital, Kabul. The fire situation is strongly connected with electrical wiring failures, non-standard heating such as coal, gas cylinders and open fire, dense chaotic buildings and the use of combustible materials in traditional and modern buildings [1]-[2]. Large fires in markets such as Mandawi, Milad and Ahmadi lead to serious economic losses, while the response of fire services is often delayed because of outdated equipment, limited access roads and insufficient resources [3]-[4]-[5].

Kabul has a special urban fire-risk profile. The dominant urban development challenge is the high proportion of informal settlements, which represent approximately 70-80% of the housing stock. These areas have narrow passages, dense traditional buildings, limited water supply, non-standard electrical networks and buildings constructed without proper project documentation [6]-[10]. In such conditions, a small fire can rapidly spread from one room to corridors, staircases and neighboring buildings.

Traditional fire alarm and extinguishing methods currently used in Kabul show low efficiency. Fire detection is often visual or by smell, while fire extinguishing usually depends on portable extinguishers, buckets of sand, water from household storage and manual intervention by residents. These methods can be useful for a very small initial fire, but they are not enough for hidden burning, night-time fires, electrical fires and multi-story residential buildings.

sThe purpose of this work is to analyze, model and develop recommendations for the use of intelligent fire protection systems in buildings in the city of Kabul to improve fire safety. The scientific contribution is the development and application of a CFD-based assessment for a typical Kabul residential building, the comparison of ASET and RSET under traditional and improved conditions, and the proposal of an adapted low-power smart fire safety framework for Afghanistan.

II. METHODOLOGY

The research was carried out using a multi-level methodology based on statistical analysis, building-typology assessment, numerical modeling and evacuation-time comparison. The object of the modeling was a typical six-story multi-family residential building representative of Kabul medium-rise housing stock. The building includes apartments, corridors and a staircase that becomes the main vertical path for smoke and evacuation.

The initial data included historical demographic and fire-technical records of Kabul for the period 2010-2025, architectural schemes and materials of the selected building, Fire Dynamics Simulator (FDS) for three-dimensional field fire modeling, Smokeview for visualization of thermal and smoke propagation, and empirical parameters for RSET calculations for 150-200 occupants.

The study considered severe fire scenarios in different building zones: an apartment room ignition, a corridor ignition and a staircase ignition. The fire hazard criteria included temperature, smoke spread, carbon monoxide concentration, visibility and the time when critical values are reached. The main safety condition used in the assessment was ASET > RSET. If ASET is lower than RSET, occupants do not have enough time to evacuate safely.

Table 1: Structure of the applied research methods (adapted from the thesis).

Research stage	Method used	Purpose of application
Geometric modeling	3D modeling	Formation of the computational domain
Fire calculation	CFD modeling	Determination of temperatures and gas concentrations
Smoke analysis	Field model	Assessment of smoke layer height and visibility
Evacuation calculation	Agent-based modeling	Determination of RSET
Benchmarking	Engineering calculation	Checking the ASET > RSET condition

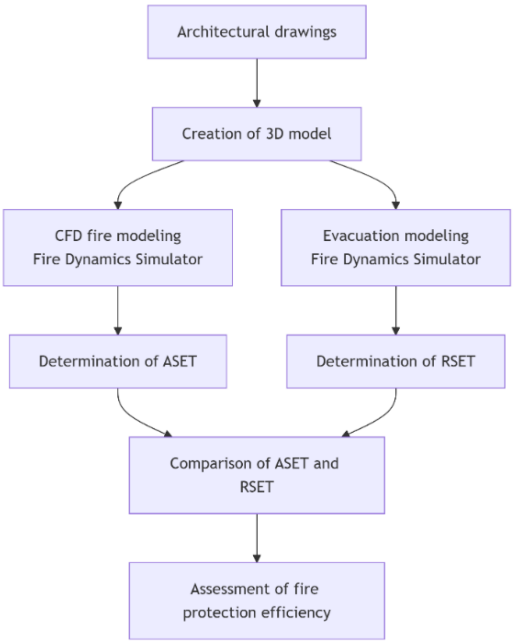

Figure 2: Algorithm of the fire-safety assessment workflow used for modeling and comparison (compiled by the author).

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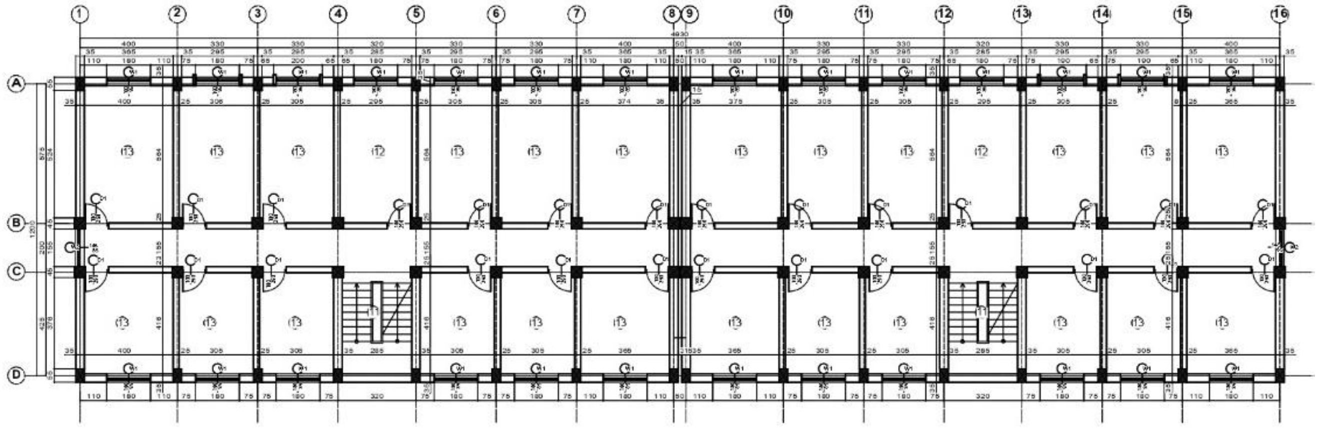

Figure 3: Floor plan of the modeled six-story residential building in Kabul (compiled by the author).

III. PRIOR APPROACH

The prior or traditional approach in Kabul buildings is mainly based on manual detection, manual notification and primary extinguishing by residents or shopkeepers. Most residential buildings, especially informal hillside settlements and old neighborhoods, do not have fixed alarm systems. Fire detection is carried out visually or by hearing: residents notice smoke, flames, a burning smell or the screams of neighbors.

The main advantage of this approach is low cost. In dense buildings, people can quickly inform neighbors by voice, and residents may react in the first minutes. However, the weaknesses are serious: late detection, no automatic warning, high probability of panic, blocked exits, low effectiveness against electrical or liquid fires, and strong dependence on fire brigades that may arrive after 20-60 minutes or more.

The regulatory framework also has limitations. The Afghanistan Building Code 2012 and the Building Manual for Afghanistan contain requirements related to fire resistance, escape routes, alarm systems and extinguishing systems, but their practical application is weak in informal settlements and many traditional buildings [11]-[13]. Therefore, the gap between written standards and real building conditions remains one of the main reasons for high fire vulnerability.

Table 2: Main causes of fires in Kabul (adapted from the thesis).

Cause / risk factor	Approximate proportion	Typical examples	Consequences
Short circuit / faulty wiring	50-60%	Mandawi market, Sarai Shahzada, Kandahar	Most common reason in bazaars and residential sector
Unsafe heating (coal, gas, kerosene)	20-30%	Residential buildings in several districts	Winter peak, CO poisoning and burn injuries
Careless handling of fire	10-15%	Kitchen fires, lamps, barbecues	Frequent in traditional yards
Gas / combustible material explosions	5-10%	Gas plants and tall buildings	Rapid development and large destruction
Dense construction and combustible materials	Reinforcing factor	Markets and informal settlements	Fire transition between buildings within minutes

IV. OUR APPROACH

The proposed approach is the use of Intelligent Fire Protection Systems (IFPS) adapted to Kabul conditions. The system is not only a standard alarm; it is a cyber-physical safety network that combines multi-sensor fire detection, IoT-based communication, automatic local response and evacuation support. The core idea is to reduce the influence of the human factor, shorten detection time and support autonomous operation when water and electricity supply are unstable.

The proposed low-power architecture includes smoke, heat, flame and gas sensors; edge devices for local decision-making; decentralized communication using low-power networks; mobile or siren-based notification; localized smart sprinklers; smoke exhaust and backup power. Because Kabul suffers from unstable power supply, the framework should use low-energy devices, battery backup and decentralized alerting rather than a single centralized control point.

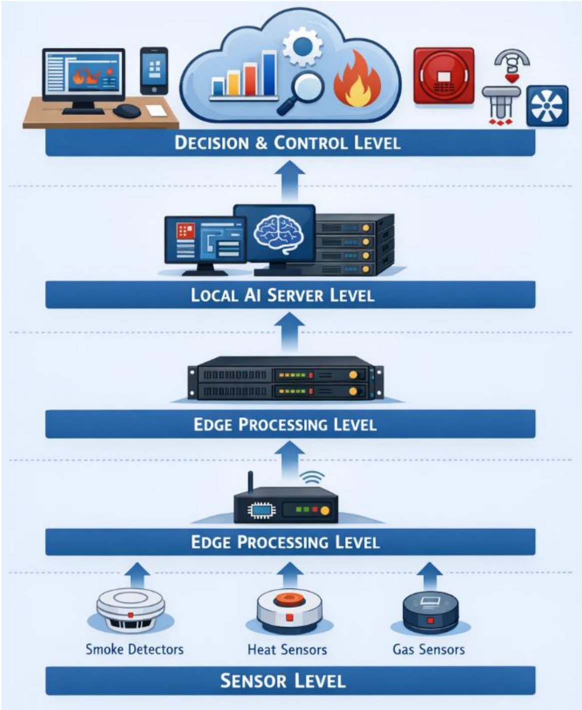

Figure 4: Multi-level architecture of an intelligent fire protection system adapted for building safety control (compiled by the author).

The numerical evaluation was performed in FDS and visualized through Smokeview. The model includes building structures, fire load, ventilation openings, corridor geometry and the staircase. The staircase is especially important because it acts as a chimney, allowing hot smoke and toxic gases to move vertically to the upper floors. The mesh size was selected in the range of about 0.2-0.5 m with refinement near the fire source.

In the baseline scenario, without intelligent systems, the apartment fire develops rapidly. Smoke enters the corridor and then the staircase, reducing visibility and increasing temperature and CO concentration on evacuation routes. For the apartment scenario, ASET was limited to 220-250 s. For the staircase fire, ASET decreased to 150-180 s because the main escape route was directly affected. RSET for 150-200 occupants was estimated at 300-400 s. Therefore, the safety condition ASET > RSET was not achieved.

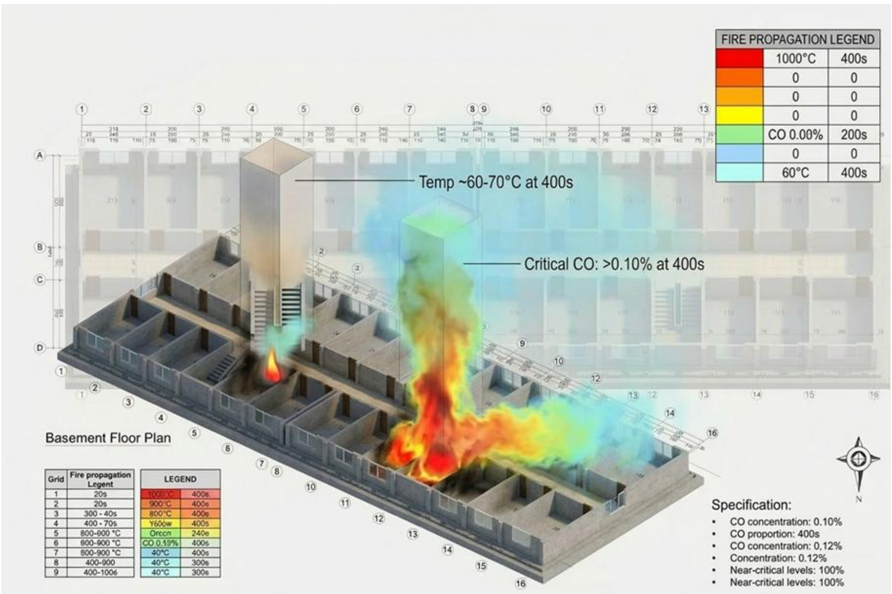

Figure 5: Smoke and fire spread in the FDS/Smokeview simulation for the modeled building (compiled by the author).

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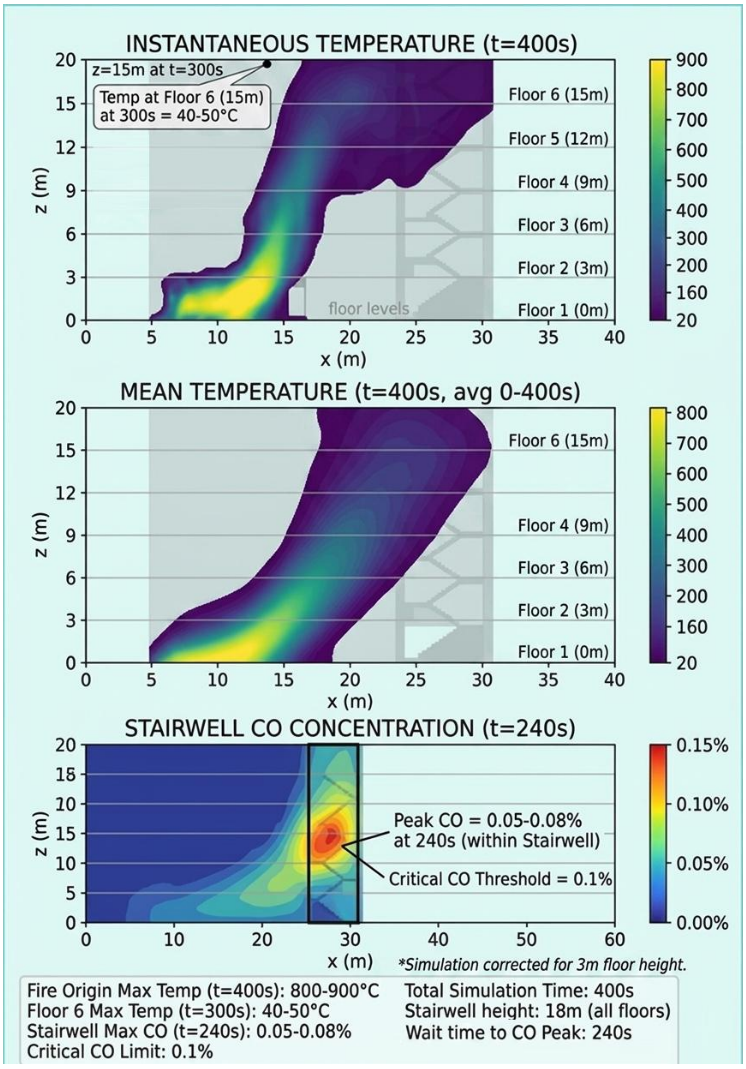

Figure 6: Calculated temperature and hazard values from the simulation results (compiled by the author).

Table 3: Comparison of traditional and intelligent fire protection performance.

Scenario / system condition	ASET	RSET / evacuation demand	Safety interpretation
Apartment fire without automated systems	220-250 s	300-400 s	ASET < RSET; evacuation is unsafe
Staircase fire without automated systems	150-180 s	300-400 s	Very critical; staircase blocked by smoke
Smart sensors + localized sprinklers	ASET increases by about 100-150 s	RSET reduced by earlier warning	Safety margin improves significantly
Sprinklers + smoke exhaust + IoT alarm	Approximately 8.5-9 min under improved conditions	Approximately 7 min in thesis conclusion	ASET > RSET; safety condition achieved
HRR control with smart suppression	Maximum HRR reduced by 40-50%	Lower heat and smoke production	Damage and evacuation risk reduced

The simulation results confirm that intelligent systems provide the most important benefit during the first minutes of fire development. Early detection gives occupants time to react, sprinklers reduce heat release and smoke production, while smoke exhaust increases visibility and protects the staircase for a longer period. For Kabul, where external emergency response may be delayed, these first minutes are the difference between an unsafe and a manageable evacuation.

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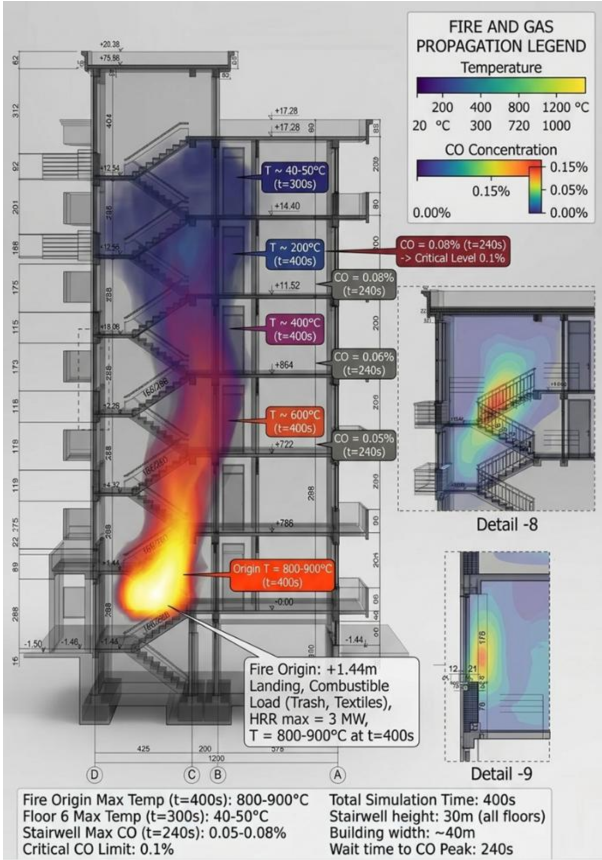

Figure 7: Fire development by stages in the vertical evacuation zone, illustrating the chimney effect in the staircase (compiled by the author).

V. CONCLUSION

This study confirms that traditional fire protection systems in Kabul buildings are not enough for safe evacuation because the existing systems cannot provide early detection, fast response and safe evacuation time. FDS and Smokeview modeling showed rapid smoke and fire spread through corridors and staircases, especially in the modeled multi-story residential building.

The single staircase creates a serious evacuation risk because smoke moves upward quickly like a chimney and can block the main evacuation route. In the baseline scenario, ASET was only 220-250 s for an apartment fire and 150-180 s for a staircase fire, while RSET was 300-400 s. Therefore, the safety condition ASET > RSET was not achieved.

The proposed IFPS framework, including IoT sensors, automatic alarms, localized smart sprinklers and smoke exhaust systems, can improve the safety margin. Sprinklers increase ASET by approximately 100-180 s, smoke exhaust systems increase ASET by about 100-150 s, and alarm and IoT systems provide earlier warning for faster evacuation. With the combined solution, ASET can increase to approximately 8.5-9 min, and the safety condition ASET > RSET can be achieved.

For practical implementation in Afghanistan, the system should be low-cost, low-power, decentralized and easy to maintain. The recommendations can support designers, developers and emergency-management authorities in Kabul in improving building fire safety and updating technical fire-safety practices.

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