*International Journal of Engineering Applied Sciences and Technology, 2025*
**Vol. 10, Issue 02, ISSN No. 2455-2143, Pages 09-12**
**Published Online June 2025 in IJEAST (http://www.ijeast.com)**

# FROM DESIGN TO DISASTER: A REVIEW OF FIRE HAZARDS IN BUILDING FAÇADES

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*Abstract:* **As urban fires become more common, there's growing concern about how building facades can contribute to the spread of flames. This article investigates the major issues and progress being made to improve fire safety by rethinking how facades are designed. It brings together insights from different fields such as architecture, material science, and safety regulations to understand how safer designs can be implemented. Many tall buildings today are still at risk because they use outdated cladding and follow weak safety policies. By reviewing recent case studies and the theories associated with façade fires, the article shows that using the right fire-resistant materials, dividing buildings into safer sections, and applying thoughtful, modern design can make a real difference. It offers practical guidance for architects, engineers, and city planners to prioritize fire safety right from the beginning of the design process helping to protect lives and communities.**

*Keywords:* **Building Façade, Cladding Materials, Fire Resistance, Fire Safety, High-Rise Buildings and Passive Fire Protection**

## I. INTRODUCTION

The Grenfell Tower fire in London (2017) has highlighted the safety risks connected to combustible façades. In most cases, traditional fire risk assessments overlook the role of façades in influencing fire behavior, such as heat transfer, flame spread, and the potential for vertical fire propagation [1]. When designed poorly or covered with flammable materials, façades can easily support vertical flame spread, thus increasing the risk and making it difficult for the emergency response teams to deal with the situation. Because cities are growing denser and architects are designing more complex high-rise buildings, it is essential to consider new fire protection approaches for tall buildings.

A façade system on a building typically includes cladding, insulation, a subframe and sometimes, cavities for ventilation. All these elements can influence the behavior of a fire during a fire-situation. When a rain-screen cladding system is used, gaps in ventilated façades often encourage vertical fire spread, thereby increasing the flame spread rate. A significant danger is that some insulation materials and ACPs containing polyethylene are highly flammable [2]. Many people are criticizing the older building codes as they hardly address the risks associated with external fire spread.

Fire safety systems in most buildings generally depended on partitions, doors, sprinklers and alarms in the past. Even though they are essential, they cannot completely control external fire spread. In the Grenfell disaster, for example, the situation was made worse due to the poorly designed façade and compartmentation strategies. As a result, a shift in fire safety is necessary, moving from focusing on the inside of a building to considering both, the interior and exterior together, including an analysis of how the façade responds in a fire.

The main concern with present façade designs is that priorities are given to their aesthetic aspect which can sometimes result in compromising on safety features. As an example, using light metal materials with plastic-filled insulation has grown popular in today's architecture since it is less expensive and more environmentally friendly [3]. However, these materials do not always resist fires unless they are specially designed for fire resistance. More emphasis on sustainability than on safety has increased the chances of fire. Therefore, when designing the exteriors of buildings, designers have to focus on several areas, including protection against fires.

Building codes are also not applied in the same way across countries. While some countries and their codes set high standards for testing buildings against fire like BS 8414 or NFPA 285, others still use older standards that ignore the ways in which various components of a façade might behave in a fire. This global inconsistency presents developers the opportunity to avoid installing proper fire-safe façades. Also, in fire testing, individual façade parts are tested which means the effects they have when working collectively in a fire are overlooked. Focus must be given on testing entire elements (by using scaled models) and reviewing the entire system to make sure the façade is safe.

For redesigning the façades of buildings to prevent fires, it is important to work together with people from architecture, fire engineering, materials science and those in charge of setting regulations. It requires more than just changing the materials used as façades are now viewed as a keyway to keep a fire under control. Important parts of a façade must include non-flammable or minimally burning materials, strong barriers in cavities, fire stops, heat-resistant paint and proper compartmentation strategy inside the buildings. Various new studies and technologies may bring improvements. Studies are now being carried out into fire-proof bio-based solutions, façades that can sense unusual levels of heat and cladding that automatically stops flames [4]. Advanced software such as BIM lets architects test various safety options for their building and improve fire safety before even starting construction. Similarly, machine learning is used to improve the accuracy of predictions of materials' performance under different fire conditions.

Yet, for new innovations to be put into practice, laws and industry practices need to be updated. Building professionals and workers should be aware of the fire safety effects of each material they use. Regulations should be adjusted to give priority to verified and certified façade systems resistant to fires. They can also encourage business owners to follow the rules by providing more favorable rates for insurance and loans. The price to install fire-resistant exterior systems is relatively low, when compared to the greater costs that fires cause to everyone.

## II. LITERATURE REVIEW

After several large fire incidents involving materials on building façades, research in the AEC fields has now given fire safety on building façades great importance. The current research mainly focuses on (1) how façade materials respond to fire, (2) different ways fire can spread across façades, (3) testing and regulation standards used globally and (4) new redesign strategies for improving fire safety on façades.

### *A.* Fire Risks Associated with Façade –

A major reason for external fire spread is the use of combustible materials in façade construction. Research has consistently shown that aluminum composite panels with polyethylene cores and expanded polystyrene (EPS) insulation in high-rise buildings are now a major fire hazard [5]. Law [6] pointed out that construction materials that match minimum building codes are not necessarily safe, given what can happen in actual fires caused by the combined effects of problems during installation and the interactions between building materials. Studies show that polymer-based insulation in façades contributed to fast flame and smoke spread if buildings were not built using appropriate subdivision techniques. Also, studies done by Pujadas-Gispert et al. [7] indicate that panels using bio-based materials or nanomaterials are showing up as options, with better resistance against heat and self-extinguishing features.

### *B.* Ways Fire Spreads in Façade

There are three common ways that façades can catch fire: (1) through flame impingement, (2) by convection in cavity spaces and (3) by radiative heat transfer from surrounding parts. In rainscreen cladding with ventilation gaps, vertical fire spread can be rapid, a phenomenon known as chimney effect, which can break through the fire separation of the walls [8]. When placed or fitted incorrectly, cavity barriers will not stop the spread of fire. Hassan et al. [9] did research using CFD software and showed that cladding and insulation that is easily flammable can allow fire to jump to several levels of a building in less than five minutes. The simulations proved that flame paths are influenced by the design of corner shapes and the presence of overhangs or vertical fins.

### *C.* Fire Performance Tests and Regulations

Laws regarding façade fire testing are not the same across the world. BS 8414 and BR 135 are used to assess how a full-scale wall assembly performs in the UK. The fire propagation features of exterior walls with combustible items in the US are regulated by NFPA 285. EN 13501-1 and EN 13501-2 in Europe, along with ISO standards, bring consistency to the testing of both fire resistance and reaction to fire for construction materials. There has been added attention to these standards as a result of the reforms implemented after the Grenfell incident. In 2018, the Hackitt Report pointed out that plenty of rules in the UK made it easy for unsafe materials to be used during construction. In their study, Zekri et al. [10] argue that system evaluations in real-time could be improved by creating new performance-related criteria with organized testing from top to bottom.

### *D.* Methods to Improve Safety

Retrofitting older building fronts is now seen as a way to modify the looks of the building. Fire safety associated with building façades can be improved in many ways:

1) Taking off the combustible panels and using non-flammable panels such as stone, metal or fibre cement instead.
2) Regularly installing horizontal and vertical fire stops to prevent flames from spreading quickly.
3) Using fire resistant coatings that can expand when heated to stop the substrate from burning.

Redesigning new façades now also involves considering fire safety at the beginning of the design process. With fire simulation software such as FDS and PyroSim, architects and engineers are able to assess various materials and designs before construction [11]. In addition, thermal sensors and responsive materials are placed along the exteriors of the building which is now becoming a new type of fire protection [12].

### *E.* Some Examples of Façade-Fire Incidents

1) Grenfell Tower: The 2017 Grenfell Tower fire in the UK killed 72 people when it spread through the flammable materials on the outside cladding. Though the cladding met initial safety standards, problems arose during use because it was installed incorrectly and did not work well with other materials.
2) Lacrosse Apartment: A Melbourne high-rise building caught fire in 2014 after the ACP cladding was caught on fire from a cigarette and the flames spread to the 13th floor in minutes. While there were no deaths in the

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incident, it was a major reason for changes to national building codes and showed what could happen with combustible façades.

3) Torch Tower: Two serious fires on the Torch Tower, Dubai (in 2015 and 2017) led people to be very concerned about the risks of fires in tall buildings covered with non-fire-rated aluminum panels. They reveal that the regulations, checks on materials and management of fire dangers in façade planning were not effective.

Fig. 1. Grenfell Tower, Lacrosse Apartment and Torch Tower [13] [14] [15]

## III. FIRE SCIENCE AND DESIGN INTEGRATION

Two key ideas are involved in fire safety for building façades: Performance-Based Design (PBD) and Fire Dynamics Theory. Understanding these theories is essential for understanding why some façade systems fail and how engineers can redesign them more effectively.

### *A.* Fire Dynamics Theory

Fire dynamics can be described as the study of how fire science, chemistry, material properties, heat transfer and fluid mechanics influence the dynamics of a fire. In façade assemblies, this means examining factors such as heat release rate (HRR), flame propagation, and airflow within cavity spaces. Take the chimney effect, for example; it is a direct consequence of fire dynamics. When a ventilated rainscreen cladding system has vertical gaps, it allows hot gases and flames to rise due to buoyancy, which can really ramp up fire spread.

This behavior can be modeled according to the principles of fire dynamics, especially for buildings where the openings in vertical cavities can act like open channels. The HRR of materials such as aluminum composite panels (ACPs) with polyethylene cores can spike quickly, exceeding critical thresholds that hinder fire stops from working properly. Studies point out that once the flame temperature hits around 500–600°C, most unprotected synthetic materials in façades begin to break down or catch fire. This highlights how the choice and arrangement of materials can significantly affect external fire spread.

### *B.* Performance-Based Design (PBD)

Performance-Based Design is an approach in fire protection engineering where design is based on realistic performance criteria, as opposed to simply following code compliance. Performance based design approach usually involves simulating fire scenarios, evaluating how quickly occupants can evacuate, and predicting how structures will behave under thermal stress. This can be done by a variety of methods including basic calculation and by using simulation software. Fire behaviors can be simulated using a range of computational fluid dynamics (CFD) software. The most commonly used software for fire simulation is 'Fire Dynamics Simulator' developed by NIST. Evacuation time and occupant behavior can be modelled using software like 'Pathfinder'. The results from such simulations can provide a more comprehensive and adaptable approach to façade fire safety.

### *C.* Interface Theory in Complex Systems

Interface theory, though less frequently cited, offers valuable insight by focusing on the junctions between different building subsystems - e.g., interfaces between cladding and windows, or between insulation and the structural wall. Fire performance on façades is generally worsened not by the failure of the components but at interfaces, where gaps and incompatibilities allow fire a pathway to bypass containment measures. The Grenfell Tower disaster, as an example, was strongly caused by such interface failures—where breakages in fire stops, insulation, and cladding did not work together as an integrated fire-resistant system.

### *D.* Holistic Risk-Based Approach

Modern fire science also advocates a risk-based theory, which combines fire load density, likelihood of ignition, and impact in one single model. Vertical stacking of combustible panels in high-rise buildings increases risk by allowing fire to jump between floors in seconds. Combining this theory with PBD makes practitioners prioritize risk reduction in design by reducing fire load on façades, improving factors of detection and suppression, and sheathing exposed sections of the building envelope.

## IV. CONCLUSION

The rise in façade-related fire incidents over the past few years really underscores the pressing need to rethink how we approach fire safety in modern buildings, particularly high-rises. This study has made it clear that façades are more than just eye-catching or aesthetic elements as they play a crucial role in a building's fire protection system. The study captured how the use of combustible materials, lack of systemic thinking, and outdated regulations have contributed to exterior spread of fire in most tragedies. By looking at the various façade materials available, modes of fire spread and varying test requirements in different countries, it is clear that prescriptive codes alone are insufficient. Therefore, it is now necessary to embrace performance-based and risk-informed strategies, along with advanced fire modeling tools, to create a more flexible and comprehensive approach. However, the effectiveness of these advances in fire science is heavily dependent on the legislation. Codes and standards must be updated to support performance-based approaches. Also, collaboration across various disciplines and efforts to increase awareness among stakeholders must be promoted. Fire-safe design must be paramount in a project from its earliest stages, not an afterthought or a tick-box exercise.

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