

Life Safety Risks Posed by New Age Interior Architecture Materials During a Fire: Evidence from Case Study Analysis

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ABSTRACT

Interior finishes are a crucial part of designing a building's interior as it transforms the basic structure into an aesthetic and visually pleasing space. Research suggests finishing materials need to perform basic functional qualities which include safety and fire resistance to ensure the health and welfare of the occupants. In present day scenario, authors see a diverse range of interior finishes with natural and synthetic materials being used in the design industry which looks beautiful but creates a serious threat on the life safety of occupants due to their easy ignition and combustion properties. A magnitude of dangerous and life-threatening toxic smoke and gases are released by these materials during the burning process. Smoke hinders the safe evacuation of occupants during such incidents due to reduced visibility or incapacitation due to prolonged exposure to the harmful effects of toxic products. This has resulted in a large number of fire deaths due to asphyxiation and later due to burns. This paper will review case studies of Uphaar Cinema Fire incident in Delhi, Arpit Palace Hotel Fire in Karol Bagh, Delhi and some very recent incidents of Fire such as TRP Game Zone in Rajkot, Gujarat deriving inferences on the toxic hazards & life-threatening risk posed by burning of flammable finishing materials used in any enclosed interior spaces.

Keywords: Interior Finishes, Toxic Smoke, Ignition, Combustion, Life Safety

INTRODUCTION

Fire hazards are a critical issue worldwide, impacting both developed and developing nations. From 2013 to 2017, the International Association of Fire and Rescue Services reported an average of 3.5 million fire incidents globally each year. In 2016, the World Health Organization highlighted that, 71 countries experienced over 300 fire-related deaths annually. The United States, with 1.3 million fire incidents in 2017, was the most affected, followed by Italy and France with 0.33 million and 0.31 million incidents respectively. The U.S. also faced \$23 billion in property damage that year but maintained a low fatality rate of 1 death per 100,000 people, demonstrating effective fire preparedness. In contrast, India, particularly vulnerable during the hot, dry summer months, reported approximately 83,872 fire incidents between 2014 and 2018, with urban areas and industrial sites being notably at risk. [1-4]

Fires generally start with ignition. In olden times, ignition used to be called inflammation, and that term is still occasionally found in some literature. When a fire is investigated, many things may be checked, but one of the essential ones is an attempt to determine the cause of the fire. To determine the cause, it is important to know the ignition characteristics of combustibles used or stored in the interior spaces.[5] As interior designers and architects it is important to study the yield of toxic gases released from finishing materials used for surface decoration and furniture installations to understand the fire load and fire toxicity of these materials in high occupancy buildings. Toxic smoke produced upon burning and combustion of inflammable materials used for interior space design is the largest cause of death and injury from unwanted fires, yet it is the least well studied area of fire science and engineering. Fire toxicity increases by factors up to 50, as the fire becomes under-ventilated. [6] Finishing materials offer a seamless and aesthetic appearance to the interior spaces. These materials in the advent of fire become fuel to the chemical process of combustion which upon release of toxic gases could prove to be fatal for life safety of occupants trapped inside. Therefore, a careful examination and

selection of interior finishing materials is an important aspect of designing spaces which could enhance the safety of occupants in buildings. Inhalation of toxic gases in smoke is the primary cause of death from fire. Bromine, a chemical element often used in flame retardants by furniture manufacturers, increases the amount of the two key toxicants, carbon monoxide and hydrogen cyanide, when furniture burns. [7] There is a significant risk to life safety in both pre- and post-flashover phases of building fires. On an average about 44,300 fire deaths have occurred every year between 1993 and 2015 [8]. During pre-flashover phase of fire, combustion generates several toxic gases which are extremely deleterious to humans and inhalation (even in small quantities) can be fatal within minutes [9, 10]. Most common among these are carbon monoxide (generated from incomplete combustion), hydrogen cyanide (generated from burning plastics), and phosgene gas (generated from burning vinyl-based household materials). Apart from toxic smoke and burning, biggest risk to life safety during post-flashover phase is partial or complete collapse of structure which can inhibit firefighting operations and kill trapped inhabitants under collapsed debris. Therefore, fire represents significant threat to life safety even when it is not fully developed, and every minute is critical in evacuating inhabitants during building fires. [5]

LITERATURE REVIEW

- a. Historically, building materials were selected based on local availability, suitability to climatic conditions, and cost. Recently, there has been a shift towards innovative materials and practices, including the use of waste products, mineral admixtures, and composite materials. Research and development have expanded to include materials designed for specific construction needs, such as those for disaster-prone or harsh environments. National standards currently use peak heat release rates to determine fire ratings, but this measure alone is insufficient for comprehensive fire risk assessment. [11]
- b. Small-scale fire tests have been crucial for evaluating the toxic potency of smoke generated by burning materials. These tests, which use rodents to determine lethal concentrations and exposure times, have revealed that carbon monoxide, hydrogen cyanide, and hydrogen chloride are significant toxicants. This research, prompted by the rise of synthetic polymers in interior finishes, has highlighted the complexity of smoke toxicity beyond just carbon monoxide. [12]
- c. In order to study change in fire properties in present scenario, numerical simulation of interior finishing materials for fire and study combinations of different materials and thickness shall be conducted. In order to generate data, to characterize and to reduce the fire load and hazards of interior finishing materials, the bench scale of the cone calorimeter is one of the most employed apparatuses. [13,14] The cone calorimeter is one of the most recognized fire testing apparatuses in the world. There are numerous parameters that can be investigated through the instrument of cone calorimeter, such as, Time to Ignition (TTI), Heat Release Rate (HRR), Total Heat Release (THR), Carbon Monoxide Production, Mass Loss Rate (MLR), and so on. [15, 16] The flammability of materials such as Poly Vinyl Chloride (PVC) membranes can be studied by the relevant experimental data of the Cone Calorimeter, and the flue gas properties of the materials can be studied by using it. To evaluate the fire safety risk factors, the ignition time is one of the most important parameters to evaluate the burning property of materials, and the shorter the ignition time of the material under the same condition, the easier the material is ignited and the fire risk is greater. [17]
- d. While current research largely focuses on the strength degradation of new materials, there is a need for more studies on toxicity and combustibility. High toxicity and combustibility increase fire risks and severity. Therefore, it is important to assess all three fire safety aspects—toxicity, combustibility, and strength degradation—to make informed decisions about new building materials. The heat hazards associated with material combustion include fire growth and heat release, and recent studies have explored the impact of wind on fire dynamics. [18 - 19]
- e. Research by Hu and others has examined how wind influences fire characteristics, including heat feedback and smoke dispersion. Understanding the effects of wind on flame behaviour and smoke flow provides valuable insights into fire dynamics in urban environments and indoor settings. [20]

- f. Studies by Tohidi, Kaye, and Tang have focused on the effects of wind on flame spread over solid surfaces. [21-24] The development of models, such as the laminar flame spread model proposed by de Ris, helps predict flame spread rates and behaviours. Research has also explored flame spread in different orientations, including inclined surfaces, contributing to a better understanding of fire dynamics. [25-27] In previous studies, much attention has been given to the horizontal, upward and downward flame spread for their frequency in fires. [28-32] After that, much of the literature addresses the ignition and combustion behaviour of various materials, including wood and cellulosic materials. Studies have investigated the impact of different factors on ignition behaviour and pyrolysis, though uncertainties remain due to variations in techniques and material properties. [33-44]
- g. PVC membranes are commonly used in temporary and semi-permanent constructions, but there is limited data on their combustion and flame propagation characteristics under stable radiation flux. Research by Patrick Van Hees and Per Blomqvist has reviewed regulations and test methods applicable to technical textiles in buildings. [45-47]
- h. Yu XI, Guo-qing ZHU, and colleagues studied the fire behaviour of PVC membranes using the cone calorimeter. Their experiments revealed key parameters such as time to ignition and heat release rate, highlighting carbon monoxide as the primary toxic gas in PVC combustion. This data is crucial for performance-based fire protection of buildings with PVC membranes. [48]
- i. Talel Fateh investigated the thermal degradation of plywood using a cone calorimeter. The study focused on monitoring mass loss, ignition times, and gaseous emissions during degradation. The results provide insights into the ignitability and combustibility of plywood and its associated risks from smoke and combustion products. [49]
- j. Anna A. Stec's research on fire toxicity has highlighted the hazardous impact of toxic effluents on human health. Her studies reveal that under-ventilated fires can significantly increase toxicity, and longer-term toxicants like carcinogenic polycyclic aromatic hydrocarbons pose serious health risks beyond acute asphyxiants. [6]
- k. Jin B. Fang's study involved full-scale room tests to evaluate the contribution of different wall and ceiling panels to fire growth. The tests measured various parameters, including gas temperatures and smoke densities, to assess fire hazards and compare results with laboratory tests. This research helps determine the potential for room flashover and overall fire risk. [50]
- l. Research by Bei Pei, Guo-yong Song, and Chang LU explored the burning performance of liquorices. Their findings indicate that liquorices ignite easily and have high heat release rates, which vary with heat flux. The study highlights the need to consider the fire risks associated with liquorices in fire safety assessments. [51]
- m. Xujuan Wu, Serge Bourbigot, Kaiyuan Li, and Yanyan Zou studied the pyrolysis and combustion of PLA-ABS blends. Their research found that PLA-ABS co-pyrolysis enhances the depolymerization of components, leading to higher heat release rates compared to individual materials. This study provides insights into the fire behaviour of PLA-ABS blends and their potential environmental impacts. [52]

RESEARCH GAP AND PROBLEM IDENTIFICATION

Combustion Behaviour and Fire Performance of new age interior finishes

Modern interior finishes have evolved significantly, driven by advances in technology and changing design preferences. Key among these are synthetic textiles, composite materials, and decorative laminates. Synthetic textiles, such as advanced microfibers and engineered fabrics, offer durability and ease of maintenance, often featuring enhanced stain resistance and innovative texture options. Composite materials, which blend various substances like resins, fibres, and minerals, provide high strength and versatility, making them ideal for applications ranging from countertops to wall panels. Decorative laminates, known for their aesthetic appeal and affordability, come in a variety of patterns and finishes, simulating natural materials like wood and stone

while offering superior durability. These new age finishes exhibit varied fire behaviour characteristics, influenced by their composition and treatment. Synthetic textiles and composite materials often incorporate flame retardants to enhance their fire resistance. However, the effectiveness of these treatments can vary, and some materials may still pose fire risks if not properly tested and certified. Decorative laminates, while generally resistant to ignition, can emit toxic fumes if they burn, depending on the specific chemicals used in their production. Understanding these characteristics is crucial for ensuring that new interior finishes meet safety standards and perform reliably under fire conditions.

Factors influencing fire growth, spread, and intensity

Several factors influence the growth, spread, and intensity of fires involving interior finishes. Material composition is critical, with flammable substances and inadequate fire-retardant treatments affecting performance. Materials are categorized by their flammability, heat release rates (HRR), and smoke production:

- Flammability:** Materials vary in their ignition susceptibility. Highly flammable materials, such as some synthetic textiles and low-density foams, can ignite quickly and accelerate fire spread.
- Heat Release Rate (HRR):** This indicates the amount of heat emitted during combustion. Materials with high HRR, such as certain composites and laminates, can significantly increase fire intensity and temperature.
- Smoke Production:** Materials that produce dense smoke can obstruct visibility and hinder evacuation. High smoke-producing materials often release toxic gases, complicating fire response.
- Fire load:** High fire loads increase both the intensity and duration of a fire, while high fuel loads contribute to faster fire spread. Additionally, installation methods (e.g., adhesive types and presence of gaps) and environmental conditions (e.g., ventilation and additional combustibles) affect how fires spread. Building codes and standards set performance levels for fire resistance, but real-world conditions can vary, making thorough testing and adherence to safety guidelines crucial.

Generation of Toxic Emissions: Identification of primary toxicants emitted during combustion and risks posed by toxic emissions on occupants.

During a fire, the combustion of materials releases a range of toxic emissions that pose severe risks to occupants. Key toxicants include carbon monoxide, which impairs oxygen transport in the blood; hydrogen cyanide, which disrupts cellular respiration; and hydrogen chloride, which irritates the respiratory system. Additional harmful substances, such as formaldehyde, acrolein, and nitrogen dioxide, can cause respiratory distress, eye irritation, and long-term health issues like cancer and chronic respiratory diseases. These toxic emissions not only impair visibility and hinder escape efforts but also pose significant health risks through both immediate exposure and long-term effects. Table 1 shows gases that are highly dangerous to the life safety of occupants. These gases if inhaled even in small quantities can lead to asphyxiation and death.

Substance	Cas no.	Immediately dangerous to Life and Death value (1994)
Benzene	71-43-2	500 ppm
<u>Bromine</u>	7726-95-6	3 ppm
<u>Carbon Dioxide</u>	124-38-9	40,000 ppm
<u>Carbon Monoxide</u>	630-08-0	1,200 ppm
Hydrogen Cyanide	74-90-8	50 ppm
<u>Phenol</u>	108-95-2	250 ppm

Table 1: Immediately Dangerous to Life and Health (IDLH) values for Toxic Gases released during fire.

Toxic gases such as Carbon Monoxide and their vapours are a leading cause of fire-related deaths, often surpassing fatalities from burns. Statistics indicate that around 50% of deaths in building fires result from toxic

combustion products, with this figure likely higher due to the difficulty of distinguishing between burns and toxic effects in severely injured victims. Smoke, consisting of fine particles and condensed vapours, primarily reduces visibility, while gases and vapours remaining gaseous or condensing upon cooling can severely impact bodily functions. Toxic gases such as hydrogen chloride and ammonia can cause respiratory irritation and eye discomfort, potentially trapping occupants and complicating evacuation efforts.

While modern fire departments are equipped with protective gear to handle these hazards, the increased use of synthetic materials in buildings has heightened concerns about toxic combustion products. As a result, building codes are now incorporating regulations to limit materials that emit more smoke or toxic gases than untreated wood or paper, aiming to enhance overall safety.

Case Studies and Incident Analyses: Review of fire incidents in India where Smoke Accumulation in enclosed spaces Toxicity has played a critical role in causing damage to the life safety of occupants.

- a. The Uphaar Cinema fire, one of the worst fire tragedies in Indian history which occurred on Friday, 13 June 1997 at Uphaar Cinema, in Green Park, New Delhi, at about 0455 PM during screening of the movie *Border* trapped inside, 59 people died, mostly due to suffocation, and 103 were seriously injured in the resulting stampede. Transformer caught fire and started leaking transformer oil spreading the fire to the adjacent parking lot where cars were parked. The result was that all the cars parked in the parking area on the ground floor of the cinema hall were ablaze. The burning cars created a lot of smoke. Since the smoke had no other place to go and it has a tendency to go upward, it started going up through the stairway to the balcony foyer. The northern bound smoke encountered a gate which was adjacent to a staircase leading to the cinema auditorium on the first floor. Due to chimney effect, the smoke gushed into the stairwell and eventually entered the cinema auditorium through a door and through the air-conditioning ducts. The southward bound smoke similarly travelled aurally through another staircase into the lower portion of the balcony of the auditorium from the left side. All this happened while a large number of people were seated in the auditorium enjoying the matinee show. Because of smoke and carbon monoxide released by the burning oil and other combustible material, the people in the auditorium started suffocating. Burning transformer oil usually also releases hydrogen and minor quantities of methane, which combined together to create higher fatalities in the case of Uphaar cinema hall.
- b. The Rajkot TRP Gaming Zone fire in May 2024 resulted in 27 deaths. Investigations reported presence of combustible materials including foam sheets, plastic mattresses and thermocol sheets, while deficiencies in access, egress and fire safety provisions were also reported (Indian Express, 2024). The incident demonstrates how the combination of combustible contents, rapid fire growth and inadequate means of escape can severely compromise occupant safety.
- c. The Vivek Vihar neonatal care centre fire in Delhi in May 2024 resulted in the deaths of new born infants. Reports concerning the incident identified deficiencies in fire safety arrangements and evacuation provisions (Indian Express, 2024). Healthcare facilities present a particularly serious fire safety challenge because patients may have limited mobility and may require assistance during evacuation.
- d. A further example occurred in Kolkata on 19th August 2026, when a fire in a building containing several hotels resulted in multiple deaths. Reports indicated smoke inhalation was suspected to be the primary cause of deaths due to inadequate ventilation and limited escape conditions hindered the evacuation process (Associated Press, 2026)

These incidents highlight the pivotal role of smoke inhalation during a fire accident. Smoke toxicity is considered to be a greater cause of deaths and casualties than burns and is therefore a deeply concerning research area for interior architects since it is being emitted from the materials used in the interior spatial design and decoration during the burning process.

DANGERS OF SMOKE ACCUMULATION IN ENCLOSED SPACES

As a compartment fire develops, hot gases rise and form a smoke layer beneath the ceiling. As the fire growth continues, this layer can descend into the occupied zone. In an enclosed or poorly ventilated compartment, the concentration of combustion products can therefore increase rapidly.

Smoke Formation and Component Fire Gases

Smoke is a complex mixture of gases, vapours, aerosols, soot and partially oxidized combustion products. Its composition depends on the chemical nature of the fuel, temperature, oxygen availability, ventilation conditions and combustion regime. Interior Architecture materials such as Poly Vinyl Chloride (PVC) and other plastic composites that are widely used in interior architecture applications including wall panels, flooring, cables and decorative finishes, is of particular interest because its thermal decomposition can release Hydrogen Chloride (HCl), while combustion can produce Carbon Monoxide (CO), Carbon Dioxide (CO₂), Hydrocarbons and carbonaceous products (Huggett and Levin, 1986). Experimental fire studies have demonstrated the presence of CO, HCl, soot and other combustion products in PVC related fire effluents (Gann et al., 2003).

Influence of Material Composition on Smoke Toxicity

The elemental composition of material strongly influences the combustion products during a fire. Carbon and Hydrogen containing materials can produce CO₂ and water during efficient combustion, while incomplete combustion can generate CO and a range of organic products. Materials containing chlorine, nitrogen or Sulphur can generate additional toxic compounds. For example, Poly Vinyl Chloride products contain chlorine and can therefore produce HCl during thermal decomposition and combustion. Nitrogen containing polymers may generate Hydrogen Cyanide (HCN) and Nitrogen Oxide (Nox) under appropriate fire conditions (Huggett and Levin, 1986).

Physiological Effects of Toxic Smoke and Fire Effluents

Smoke may reach occupied areas before flames do, resulting in occupants being exposed to hazardous conditions even when the fire itself is physically distant. Smoke represents a combination of visibility, respiratory and toxicological hazard. Carbon monoxide (CO) is particularly significant because it interferes with the body's ability to transport oxygen. Other fire gases can cause respiratory irritation, neurological impairment or systemic toxicity. In addition, soot and other particulate matter can substantially reduce visibility and contribute to respiratory exposure (Gann et al., 2003; Hugget and Levin, 1986).

CONCLUSION

Modern homes filled with synthetic materials can reach deadly conditions much faster than those with natural furnishings, highlighting increased fire risks and the importance of fire safety awareness and training. Several experiments have been conducted as part of this research for a detailed comparison study to demonstrate how different home furnishing materials influence fire behaviour. Experiments have been conducted by recreating a side-by-side burn test using two identical room setups one furnished primarily with synthetic materials and the other with natural materials. Initial experiments show, the synthetic room contained items such as polyester-covered furniture, polyurethane foam cushions, plastic objects, engineered wood, and synthetic carpeting. In contrast, the natural room featured cotton-based upholstery, solid wood furniture, hardwood flooring, and fewer synthetic elements. Despite similar layouts and ignition conditions, the fire development in each room differed significantly due to the materials used.

A key concept highlighted in the study is flashover, a critical stage in fire development where nearly all combustible surfaces in a room ignite almost simultaneously after being exposed to intense heat (around 600°C). The results consistently showed that the room with synthetic furnishings reached flashover much faster than the one with natural materials. Synthetic items, particularly foam and plastics, burn rapidly and

release large amounts of heat, accelerating fire growth. This leads to a quicker transition to dangerous conditions, drastically reducing the time available for occupants to escape.

Additionally, the study emphasizes the role of smoke and toxic gases produced during a fire. As materials burn, they consume oxygen and release harmful combustion products. These gases can spread quickly throughout a home, potentially incapacitating occupants even before flashover occurs. This means that in modern homes filled with synthetic materials, the danger is not only from flames but also from the rapid buildup of toxic smoke. These experiments served as a powerful visual demonstration of how modern synthetic furnishings have changed the fire environment, making fires more dangerous than in the past. They confirm earlier findings and provide clearer, more impactful visuals to support firefighter training and public education.

In conclusion, the study highlights a critical shift in residential fire risk: homes with synthetic furnishings experience faster fire growth, quicker flashover, and more hazardous conditions compared to those with natural materials. This underscores the importance of fire safety awareness, early detection systems like smoke alarms, and quick evacuation planning to reduce the risk of injury or death in residential fires.

Interior Designers must work for making buildings that support human health and safety by choosing appropriate finishing materials. Whether a project is large or small, the interior designer benefits from an awareness of the impact it will have on the welfare of its users and the community of which it is part. Finishing materials used by Interior Designers in their projects include the materials used for the exposed face of the walls and ceilings of a building and are not limited to structural materials. Interior finishes include the materials used for the exposed face of the walls and ceilings of a building and are not limited to structural materials. They can include: plaster, gypsum wallboard, wood panelling, ceiling tiles, plastic, fibre board, wall coverings including decorative furnishings, vegetation, and draperies. The selection of materials is restrained by codes and regulations that have been instituted to ensure the public's safety. For example, interior materials can either contribute potential fuel to a fire or resist ignition and flame spread.

In India, the National Building Code deals with safety from fire recognizing that safety of life is more than a matter of means of egress and accordingly deals with various matters which are considered essential to the safety of life. Early building codes focused primarily on the structure of the building, namely the construction materials and the structural system. Over time, more attention has been given to the fire behaviour characteristics and layout of materials used for the interior finishing. The behaviour of fire in buildings is influenced by a number of factors, including some not directly related to the basic construction or occupancy of a building.

RECCOMENDATIONS

Interior finishing materials are a potential cause of escalating the fire hazards in residential homes. Interior designers need to understand the fire risk characteristics of interior finishing materials used for residential buildings. The fire and life safety risks can be mitigated through efficient design and integration of active and passive fire protection measures along with smoke management. Therefore, it is recommended that:

- a. A fire rating system for all interior materials maybe introduced which comprehensively takes into account the rapidity of fire spread and toxicity.
- b. Interior Designers/ Architects must share overall fire risk factor based on interior materials.
- c. The fire audits of buildings with higher occupancy must grade the overall fire and life safety risk based on not only the fire load but the toxicity of interior materials.

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