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Analysing Green Building Design Features in the Context of Fire Risks

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Abstract

In green buildings with sustainable goals such as energy and resource conservation, user comfort, and minimal environmental impact, in the event of a possible fire, all functional components are destroyed, the building is disposed of, and economic, ecological, and social problems arise. Green buildings have design features that utilize climatic data at the highest level, use materials with low thermal conductivity and high resistance to heat transfer, and have systems that generate energy and provide energy efficiency. Problems such as combustible materials arising from these features of green designs, vertical and horizontal gaps that cause the spread of toxic gases, and malfunctions caused by electrical systems may pose a risk in the context of fire safety. In this direction, within the scope of this study, green architectural design features are analysed under 5 main headings: land, shell, material, vertical internal gaps and building systems, and energy generating systems by using the literature. 5 main headings and fire safety problems arising from subheadings are explained, and risk levels are determined. A guide for the building sector and academic studies is presented due to the risk levels and solution strategies determined as high, medium, and low and differentiated for each green design feature.

1. INTRODUCTION

Green buildings are designed, constructed, operated, refurbished, and disposed of using sustainability principles to protect the comfort and health of occupants and minimize the built environment's impact on the natural environment. However, fire safety is emerging as an important issue in green building design, which prioritizes efficiency and conservation of resources throughout the building lifecycle, particularly energy and water. In cases where the fire risk cannot be identified, and solution strategies cannot be developed from the first stages of the design, problems arise that contradict the sustainability principles of green buildings. Fire events that threaten the life safety of building occupants and firefighters, as well as the conservation of resources, should be given consideration and are more significant in green building designs with sustainability goals.

It reveals the green building design features and risk factors that pose a fire risk in the research studied or supported by international public and private organizations that address fire safety issues in green buildings and primarily produce fire safety studies. A working paper supported by the Building Research Association of New Zealand (BRANZ) and focusing on the New Zealand construction industry analyzed the conflicts between sustainable building design and fire safety design. The study presented two perspectives: the positive contribution of fire safety design to sustainability and the fire safety problems arising from sustainable design. In the report, green building design elements and systems that may pose a fire risk were classified as shell elements, intelligent building systems, alternative energy systems, landscaping, building cavity, green roofs and walls, double skin facades, curtain wall facades, atriums, heating cooling ventilation systems, shading elements [1].

The study, conducted at Worcester Polytechnic Institute and supported by the Fire Protection Association (FPA) Australia, identified linkages, challenges, and conflicts between stakeholders and developed

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recommendations for FPA Australia based on interviews with fire safety professionals, sustainable design stakeholders and review of previous work. As a result of the study, an action plan has been prepared to increase the communication between sustainable design and fire safety design and can be developed by FPA Australia. Green building design features that cause fire risk were classified as structural elements and systems, interior elements, alternative energy systems, building interior gaps, green roofs, and shading elements [2].

The report of a project supported by the National Fire Protection Association (NFPA), which presented general approaches to the issue of fire in green buildings, evaluated green rating organizations and national green building and energy codes in the context of fire and other risk factors. As a result of the studies conducted with many organizations in the United States of America (USA) and internationally, including code officials, fire departments, insurance companies, and research institutions, the project team identified green architectural features that posed a risk and developed a series of risk and system analyses related to green features and potential fire hazards that can be incorporated into certification programs. The final report of the same study, updated in 2020, examined developments in green buildings since the first report and looked at fire incidents in recent years. The report classified green building design elements and systems that may pose a fire risk as structure, shell, interior elements, intelligent building systems, alternative energy systems, landscaping, and shading elements [3,4].

Another report, supported by the National Association of State Fire Marshals (NASFM), examined fire risks in green buildings in the context of their impact on firefighters working environment, and a study has been conducted to maximize occupant and firefighter safety. It was explained that problems such as green areas and pedestrian priority roads restricting firefighter access, high fire load effect due to flammable insulation and glass types, fire outbreaks due to electrical failures from power sources such as photovoltaic panels using solar energy. At the end of the report, a checklist was produced that identifies green building components and links each element to a set of potential concerns. The report classified the green building design elements and systems that create fire risk as shell elements, intelligent building systems, alternative energy systems, site selection and use, thermal insulation materials, heating, cooling, and ventilation systems, and shading elements. [5].

A project at Worcester Polytechnic Institute, supported by NASFM, interviewed experts in green building and fire safety, analyzed, and evaluated presentations at a fire symposium. Problems such as fire risks of green building design elements and materials, lack of knowledge of fire brigade personnel, lack of coordination between disciplines, and overlap of fire-related legislation with green building design were identified. Green building design elements and systems that may pose a fire risk in the project were classified as structure and shell elements, building interior gaps, green roofs, green walls, atrium, and thermal insulation materials. [6].

A fire safety study in 50 green buildings certified by the New Zealand Green Building Council identified green architectural features that could pose a fire risk. Based on the final report of green design features discussed in a panel, prototype designs were created and numerically analysed using computational fluid dynamics. As a result of the panel, the green building design elements and systems that pose a risk were classified as intelligent building systems, alternative energy systems, green roofs and walls, double skin facades, thermal insulation materials, and atriums [7].

A study analyzed the relationship between fire safety and sustainability in buildings, addressing the energy and environmental benefits and the fire risks associated with changes in materials, products, design, and implementation in green building designs that were rapidly growing in the building industry. The study discussed the state of the fire safety and sustainability communities and suggested ways to implement to promote fire-safe sustainable design. The study classified green building design elements and systems that pose a fire risk, such as intelligent building systems, alternative energy systems, building interior gaps, thermal insulation materials, heating, cooling ventilation systems, and shading elements. [8].

In a study of high-rise buildings with green architectural features in Hong Kong, fire risks in high-rise buildings were identified and analyzed to optimize fire prevention management. Within the scope of the article, the contradictions and deficiencies between fire safety regulations and the current trend in green building design have been analyzed. The article classified green building design elements and systems as building gaps, double skin, curtain walls, and thermal insulation materials [8].

The green architectural design elements that cause fire safety problems that have been addressed in projects, reports, and other academic studies are summarised in Table 1. This study provided a detailed analysis of the fire safety issues raised by green architectural features. At the end of this study, the importance levels of the green architectural features from the start of the fire to the extinguishing phase, which is critical in the fire, were revealed.

Table 1. *Green architectural features that pose fire risk according to reference academic studies*

First author name	Structure elements and systems	Shell elements and systems.	Interior elements and systems	Intelligent building systems	Alternative energy systems	Land selection and utilization	Landscape	Interior gaps	Green roofs and walls	Double skin façades	Curtain glass facades	Atrium	Recycling storage areas	Thermal insulation materials	heating, cooling ventilation systems	Shading elements
Robbins et al.		X		X	X		X	X	X	X	X	X			X	
Roberts et al.				X	X			X						X	X	X
Carter et al.	X		X		X			X	X							X
Meacham vd.	X	X	X	X	X		X									X
Murphy et al..		X		X	X	X								X	X	X
Joyce et al.	X	X						X	X			X		X		
Donn v et al..				X	X				X	X		X	X			
Ho et al.								X		X	X			X		

2. THEORETİCAL FRAMEWORK: GREEN BUİLDİNG DESİGN - FİRE SAFETY

The design features in Table 1, identified as problems in the studies produced or supported by international organizations on fire safety in green buildings, were arranged as in Table 2 to examine them systematically within this scope of the study. The fire risks posed by these design features were identified and their impact levels were categorized in terms of fire service access, extinguishing system, fuel contribution, ignition, fire growth, smoke spread, structural stability, smoke extraction, explosion hazard, and human evacuation.

Table 2. *Classification of green architectural features that pose a fire risk*

Site	Shell	Interıor vertıcal gaps	Buıldıng systems and power supplıes	Material
Building form	Façade movement	Atrium	Photovoltaic panels	Structure material
Building orientation	Single layer curtain glass	Gallery	Solar tubes	Shell material • Insulation element • Cladding element
Landscape • Plant • Equipment • Permeable surface • Waste storage area	Double skin façades	Shaft • Installation shaft • Ventilation gap	Air conditioning systems	
	Green roof and wall			

2.1. Site

For building form, orientation, and landscaping designs suitable for green design, factors such as climatic data, built environment relations, human access, and use, use of plants ideal for the region, and creation of green areas are discussed.

Building form and orientation:

Building form, defined by building orientation and dimensional proportions, roof type and slope, façade type, and façade movement in response to natural resources such as wind and sun, influences building energy performance to make the most of climatic data [10]. The design of the form and orientation of green buildings, if not integrated with fire safety design, limits the access and working areas of firefighters. In addition, there are risks of fire spread due to wind and temperature effects. For energy-efficient building design, the form, placement and orientation of shading elements limit the access of firefighters (Figure 1) [5].

Figure 1*. Effect of shading elements and trees on firefighters' access [5]*

Landscape

Materials and landscape design criteria such as native, low water demand plants and materials, permeable concrete, high-efficiency subsurface drip irrigation, and grey water irrigation are used in green building designs. Firefighters’ access to the entire building is restricted due to trees, fountains, and landscaping equipment close to each other and the building. In addition, design problems such as insufficient load-bearing capacity of permeable concrete or asphalt surfaces used in the terrain affect Firefighters’ operations. Facilities that are not regularly maintained provide fuel for fires [5]. Reactive materials in temporary landfills set up around buildings for waste recycling have the potential to ignite [10] (Figure 2).

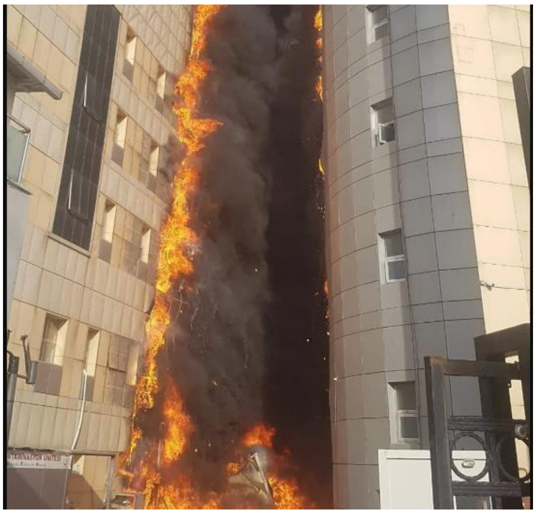

Figure 2. *The growth of the fire that started in the waste storage area [11]*

2.2. Building shell

The building shell, which consists of all horizontal, vertical, and inclined building components and acts as a filter between the outdoor and indoor environment, is an important building component that provides energy performance and indoor comfort quality [12]. In this direction, since the behavioural models differ from each other in terms of the risks posed in case of fire, the title of the shell is examined as; facade movements, single-layer curtain glass facades, double-layer facades, green roofs, and vertical elements.

The movement of the building façade

The movement of the building facade increases the building area receiving natural light and ventilation. In hot, humid climates, natural ventilation designs allow cooling with wind-induced air flow by utilising the prevailing wind direction. Thus, the amount of cooling load of the building with mechanical air conditioning systems is reduced, indoor thermal comfort is provided at desired levels and indoor air quality is improved [13]. In the event of a flaming fire in a room facing a space with façade movement, smoke, flame and other gases have the risk of spreading from the windows to the interior spaces. The chimney effect and wind accelerate the spread of smoke and toxic gases from the cavity [14] (Figure 3). Facade movement also makes it difficult for firefighters to access and extinguish the fire.

Figure 3. *Chimney effect and fire spread due to façade movement [15]*

Single layer curtain glass

In green building designs, single-layer curtain glass facade is used especially in high-rise buildings due to energy efficiency, indoor comfort, ease of production and installation. Fire safety problems occur in high-rise buildings where curtain wall systems that provide natural lighting and ventilation are used and where human density is high [15]. Facade fires are effective in the growth of fires occurring inside the building by spreading between floors and neighbouring buildings. The facade's geometry, carrier system selection, construction materials, and application details constitute the risk areas in ensuring the fire safety of multi-story buildings with large surface areas [16].

The structural elements consisting of metals with low melting points such as steel and aluminium, the excess of façade gap ratios that create largely unprotected façade surfaces, the presence of a large number of joints that allow the passage of smoke, flame, and flammable gases between floors, the preference of combustible materials such as plastic foam with high smoke and toxic gas emission capacity as filling material are the factors that create fire risk. In recent years, several fires have occurred in high-rise buildings due to curtain wall insulation and coatings, resulting in loss of life and property damage. In these fires, in addition to upward propagation due to pressure differentials and the rise of heated air, the problems of flammable insulation materials continuing along the building envelope have been observed [17].

Double skin façades

Double skin facades, which consist of a pair of shells, separated by an air gap and are generally preferred in high-rise buildings, provide thermal insulation, reduce wind pressure, and allow natural ventilation by allowing windows to be opened even on the upper floors [18]. Double skin façade systems are designed as box type, shaft type, corridor type, and building height type (continuous type), the fire propagation directions of different types differ (Figure 4).

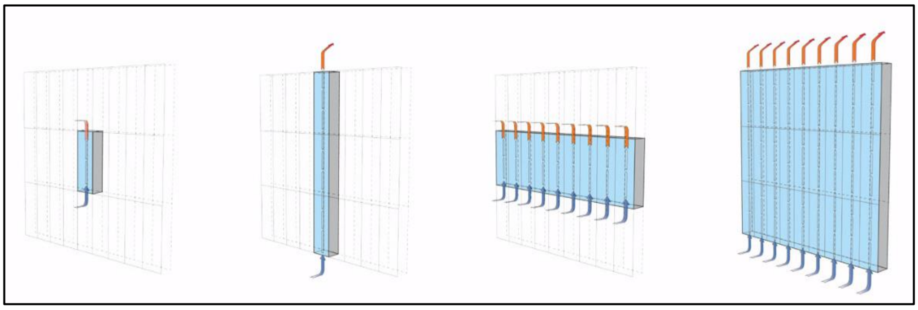

Figure 4. *Different double skin designs a-d (from left to right) a-box type, b-shaft type, c-corridor type, d-continuous type [20].*

As the ventilation gap is uninterrupted vertically and horizontally in the shaft and building height type (continuous type), fire are spread between storeys. In the corridor type double skin façade at floor level, the ventilation gap continues continuously around the same floor, although it is interrupted at floor levels. This situation causes the fire to spread to the volumes on the same floor through the ventilation corridor (Figure 5) [21].

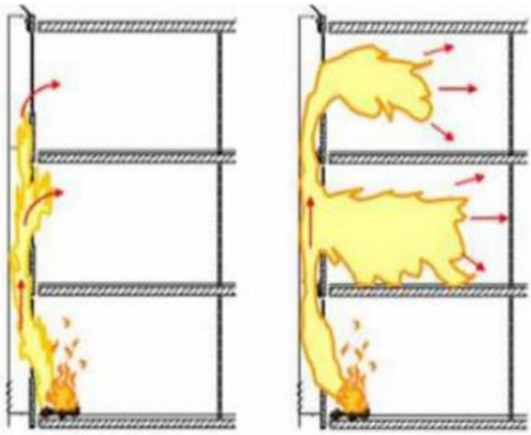

Figure 5. *Fire propagation in different double skin designs [21]*

Green roofs and walls

Green wall and roof systems created by growing plants in vertical and horizontal sections of the building shell are preferred due to their benefits, such as their contribution to biodiversity and the natural environment, providing a natural drainage system by absorbing rainwater, preventing air pollution by absorbing harmful particles and gases, contributing to the reduction of the urban heat island effect, being effective in carbon dioxide-oxygen exchange and acting as a sound absorbing element in sound insulation [22].

Green roofs consist of many components such as insulation, waterproofing membrane, protection boards, root barrier, and drainage layer, which may include water retention boards, geotextile felt, various filters, and growing vegetation. The drying out of this multi-layered system without regular maintenance, the flammability of the components, and the absorption of water used for fire-fighting have negative fire safety implications [23]. The fact that the systems used for planting in vertical areas generally have a plastic, rubber, or wooden skeleton system increases the amount of flammable material in the building. In contrast, the gap between the skeleton system and the wall forming the building facade causes the chimney effect and causes the fire to spread upwards (Figure 6) [24].

Figure 6. *Fire risks in planting systems [24]*

2.3. Building interior gaps

In green building designs, the vertical interior gaps provide a controlled circulation of the air currents generated within the building to the spaces. Internal gaps are also used to ventilate spaces that are not adjacent to the façade, to vertically transport electrical and mechanical systems, to provide lighting, ventilation, and airflow control in designs that create uninterrupted spaces between floors, such as atriums and galleries. In this direction, internal gaps are analysed as shaft, atrium, gallery and solar chimney.

Shaft

Shaft gaps are used for natural ventilation and lighting of spaces not adjacent to the building façade and vertical distribution of electrical and mechanical systems. Fire risk occurs since the shafts create uninterrupted gaps between floors and allow the chimney effect. For example, a fire that starts at the panel outlet amplified by the cables in the shaft and spread through the gap to the rest of the building, causing cumulative damage (Figure 7). If a fire that starts in a room adjacent to the shaft reaches the shaft, it spread upwards and enter the spaces through the gaps it finds [14].

Figure 7. *As a result of a fire that started in the electrical shaft in the Windsor Tower [25].*

Atrium

Natural ventilation and lighting are effectively used in atriums, defined as two or more story-high spaces with a large and vertical volume surrounded by usage areas. The primary purpose of natural ventilation in the atrium is to maintain a low indoor temperature by removing heated air from the upper levels of the atrium in hot weather and to transfer the hot air accumulated in the upper levels of the atrium to other spaces in cold weather. Since the chimney effect and wind are important factors in the fire spread, the upward reach of fire in atrium areas is easy and fast (Figure 8).

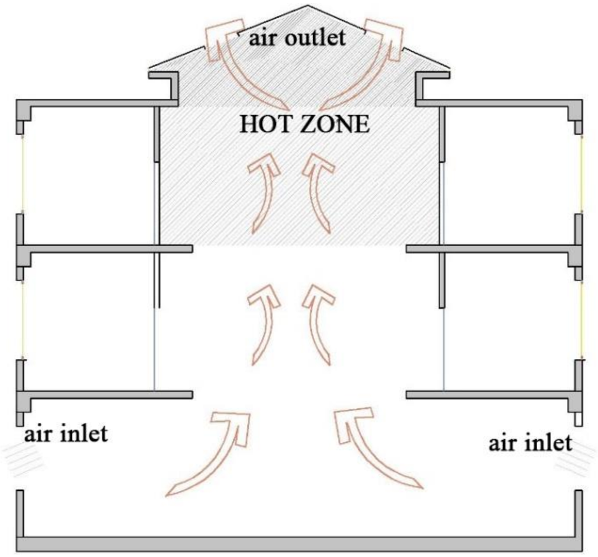

Figure 8. *Principle of rising of the heated air in the atrium by the chimney effect*

The risk of fire is also relatively high due to the high flammable material load, the number of people in the usage areas surrounding the atrium, and the presence of escape routes. Since atriums are wide openings where smoke can spread, smoke spreads rapidly due to fires that occur and fills this section quickly. Smoke and hot gases resulting from fire fill the atrium space speedily and shorten the visibility distance, do not allow fire intervention, and pose a risk with smoke transmission to the neighbouring volumes surrounding the atrium.

Gallery gaps

Similar to atriums, gallery gaps, which are defined as the gaps left between floors in buildings, are preferred in green building designs in the context of increasing space quality, natural ventilation, and lighting. The air entering the gallery spaces through the chimney effect rises rapidly, allowing the heated and polluted air to exit the spaces facing the gallery [26]. There are risks because the fire that starts in a space facing the gallery gap passes to the gallery gap and then passes to the connected spaces upwards and horizontally.

2.4. Buıldıng systems and power supplıes

In green building design, systems that generate energy or provide efficiency through solar power and techniques that contribute to the heating and cooling load of the building through mechanical systems pose a fire risk. Accordingly, photovoltaic panels, solar tubes, and air conditioning systems are considered under this title.

Photovoltaic panels

Photovoltaic panels (PV), one of the leading renewable energy sources with technological developments and producing electrical energy by using solar energy, have been used especially on building roofs in recent years. PV systems consist of polymer-supported glass plate modules, the smallest of which is the solar cell, and aluminium wire panels, to which the modules are connected with cables, as shown in Figure 9. Due to the flammable materials in PV systems, the fuel contribution to the fire, and the fact that they remain at high temperatures by retaining the solar heat due to their working principles, cause the fire to reach the PV systems quickly [27]. In addition, since PV systems cannot be deactivated, it makes it difficult to extinguish the fire because it creates the risk of electric shock in case of fire [28].

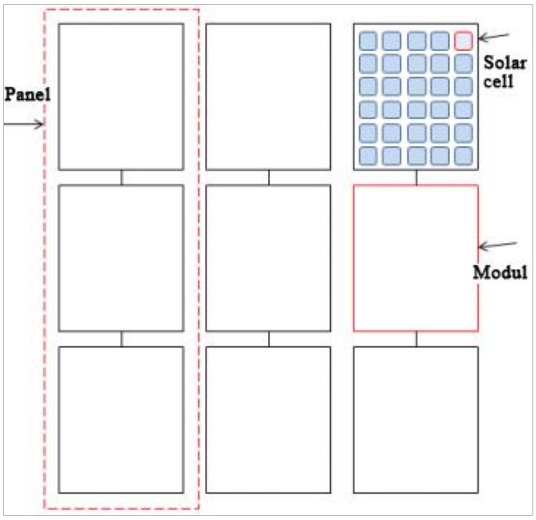

Figure 9. *PV panel and its components [28].*

Solar Tubes

The solar tube is a technological system that takes daylight from the outdoor environment in a controlled manner, carries and spreads it indoors, and provides comfortable lighting by making the disadvantages of daylight advantageous thanks to its structure [29]. In the event of a fire in a room with a solar tube, which is a kind of shaft cavity, due to the improper insulation of the tube, the fumes enter the tube, creating a risk of upward movement and causing the smoke to spread.

Air conditioning systems

Active air conditioning systems that provide heating, cooling, and ventilation with mechanical systems to provide comfortable indoor air conditions to users in closed spaces are used intensively, especially in public buildings with the development of technology. Heating, cooling, and ventilation systems with units installed in suspended ceilings provide continuity between the suspended ceiling and ceiling, creating uninterrupted horizontal areas between the rooms [30] (Figure 10). The gaps in the areas where the ventilation ducts pass through the walls, floors, and ceilings are risky for spreading smoke. In addition, if the air conditioning system is not switched off at the time of the fire, it is difficult to extinguish the fire due to the continued flow of fresh air to the fire scene.

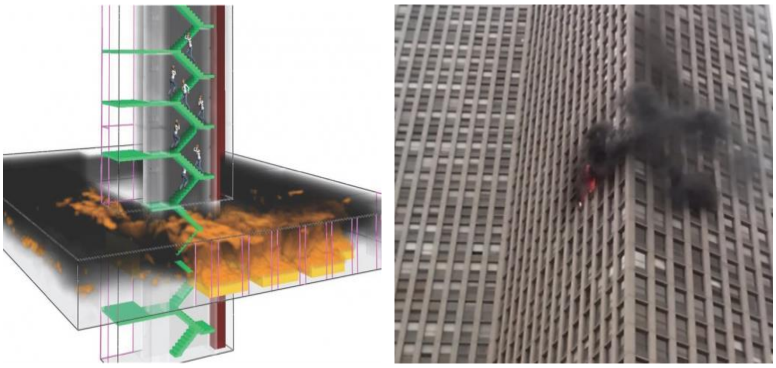

Figure 10. *Example of fire spread with horizontal continuity of the Air conditioning systems in the Cook Country Administration Building [31]*

The safest way to prevent smoke spread from the ventilation system is to provide independent systems for each fire compartment or to separate each compartment with fire dampers. The alternative to using fire dampers and separating the system is to keep the exhaust fan (or a special fan designed for smoke extraction connected to the exhaust branches) in operation during a fire and close the intake system to the fire compartment [32].

2.5. Building materials

Ignition temperatures, heat and temperature conduction properties, flammability times, thermal expansion properties, mass losses, and heat and smoke formation of the materials that contribute fuel to the fire affect the start and growth of the fire. The subject of materials in the context of both green building design and fire safety has found a broad research area, the material areas classified as shell, and structure elements in the research in the context of fire safety are summarised under this title.

Structure materials

While reinforced concrete, steel, timber, and composite structural systems are commonly used in buildings, the structural systems used in green buildings vary according to the objectives. Although steel is a non-combustible material, it loses structure properties when it reaches critical temperature and loses its mechanical properties at very high temperatures. While the yield limit of steel falls to the order of safety stresses around 400 ºC, it falls below the safety stress at 600 ºC, which is easily reached in fires [33].

In reinforced concrete structures, it is important not to expose the reinforcing steel, considering the material's behaviour at high temperatures. As a result of cracks in concrete, steel reinforcement conducts heat rapidly, increasing the temperature difference and causing the reinforcement to lose its strength. By selecting the appropriate aggregate and cement for the thermal conductivity value of concrete, the structure stability period of the reinforced concrete system is increased. [34].

Wood is used in the building sector as a long-lasting, sustainable, nature-compatible, recyclable material with good durability. The duration of reaching the core layer, which is the main structure of wood, affects the duration of strength, and when the wood burns, it emits toxic gases to the environment, and the surface begins to char. Since the charring of the wood delays reaching the core layer of the structure and the thermal conductivity value of the charcoal layer is small, it causes complete combustion and prolongs the stability period of the structure. [35].

Shell

As a result of technological developments and new perspectives on sustainability, building shell insulation, coating, and shell construction materials have developed. The most important of the fire risk factors related to the shell are heat insulated buildings with low total thermal transfer value. Better insulation of the shell with appropriate building materials will reduce the heat lost from the compartment in the event of a fire, so the heat radiated from the fire is trapped in the compartment, increasing the probability of flashover. In addition to the risk of flashover in thermal insulation materials with low thermal transfer value, another problem that should be evaluated is the danger of fire spread due to the flammability of the materials [36].

The final cladding elements are the part in the outermost layer of the shell that is most affected by environmental factors at the highest level. Systems such as glass surfaces, composite cladding elements, green walls and roofs, shading elements, and photovoltaic panels create problems such as fuel contribution to fire, explosion at high temperatures, and effect in fire intervention when used on the facade [37].

3. EVALUATION OF THE RISK LEVEL

It is seen that the main effects of green architectural design features on fire safety design are;

- Land use and building form design affect firefighter access and the extinguishing process,
- Providing fuel additive to the fire due to the properties of the material and electrical systems,
- Development and growth of fire due to material, building shell and vertical gap design,
- Risks of human evacuation, explosion effect and destabilisation of structural elements,

In this direction, a fire risk matrix was designed to systematize and summarise the risk factors described in the study.

Fire risks arising from green architectural features are categorized and explained in detail. It is seen that the impact levels of architectural design features on fire safety differ. In this direction, within the scope of the study, the impact levels of green architectural design features on fire safety were determined to present priorities for fire safety in the design stages for related academic studies and the building sector. Three impact levels, namely high level, medium level, and low impact level, were determined, and evaluations were made for 11 fire risk elements selected below:

1. Firefighters access
2. Extinguishing system
3. Fuel additive
4. Ignition
5. Fire growth
6. Smoke spread
7. CO2 amount
8. Structural stability
9. Smoke extraction
10. Explosion hazard
11. Human evacuation

In Chapter 2, fire risks arising from green architectural features were analyzed under five main headings and 14 subheadings as site, shell, interior gaps, building systems, and power supplies and material. In the analyses made, it is seen that the risk factors caused by each sub-heading vary. For example, among the risks analyzed under the landscape sub-heading, plan and equipment primarily restrict fire brigade access. At the same time, waste storage area causes fire starts due to the presence of flammable materials. In this direction, the design criteria examined under the headings have different areas of influence on fire. The matrix prepared by utilizing the studies in the literature for the impact levels of the green architectural features described in Chapter 2 on the 11 risk factors determined above in case of fire is given in Table 3. In order to make optimum use of climatic data, the primary risk posed by the design criteria for the placement of the building on the site and the landscaping and landscape elements used is the effect on firefighting operations. The external vertical gaps formed by the gappy building form, which allows for energy efficiency by optimum use of the sun and wind, pose a risk for the growth and spread of a potential fire. In this direction, the landscape design and the building's placement on the land should allow the fire brigade access to the entire building. Adequate areas should be provided around the building for access by fire-fighting vehicles and firefighters, and the materials used in these areas should have sufficient load-bearing capacity for high-tonnage vehicles.

Table 3. *Green architectural features and fire risk matrix*

🔴 high impact 🟡 medium impact 🟢 low impact	Firefighters access	Extinguishing system	Fuel additive	Ignition	Fire growth	Smoke spread	CO2 amount	Structural stability	Smoke extraction	Explosion hazard	Human evacuation
Site											
• Building form	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🟡	🟡	🟡	🟡
• Building orientation	🟡	🟡	🟢	🟢	🔴	🔴	🟢	🟡	🟡	🟢	🟡
• Landscape	🔴	🔴	🔴	🔴	🟡	🟡	🔴	🟢	🟢	🟢	🟡
➢ Plant	🔴	🔴	🔴	🔴	🟡	🟡	🔴	🟢	🟢	🟢	🟡
➢ Equipment	🔴	🔴	🔴	🔴	🟡	🟡	🔴	🟢	🟢	🟢	🟡
➢ Permeable surface	🔴	🔴	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
➢ Waste storage area	🟡	🟡	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🟢	🟢
Building Shell											
• Façade Movement	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🟡	🟡	🟡	🟡
• Single layer curtain	🟡	🟡	🟡	🟡	🔴	🔴	🟡	🔴	🟡	🔴	🟡
• Double skin façade	🟡	🟡	🟡	🟡	🔴	🔴	🟡	🔴	🟡	🔴	🟡
• Green roof	🟡	🔴	🔴	🔴	🟡	🟡	🔴	🟡	🟡	🟢	🟡
• Green wall	🟡	🔴	🔴	🔴	🔴	🔴	🔴	🟡	🟡	🟢	🟡
Building Material											
➢ Structural element	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟡	🟢	🔴
➢ Insulation element	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟡	🟢	🟡
➢ Cladding element	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟡	🔴	🟡
Interior Vertical Gaps											
• Shafts	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🟢	🔴	🟢	🔴
➢ Installation shaft	🟢	🟢	🟢	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🟢
➢ Ventilation gap	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🟢	🔴	🟢	🟢
• Atrium	🟡	🟡	🟢	🟢	🔴	🔴	🟢	🟢	🔴	🟢	🔴
• Gallery	🟡	🟡	🟢	🟢	🔴	🔴	🟢	🟢	🔴	🟢	🔴
Building System											
• Photovoltaic panel	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🟢	🟢
• Solar tube	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🟢	🟢	🟢	🟢
• Air conditioning system	🟢	🟢	🟢	🟢	🔴	🔴	🔴	🟢	🔴	🟢	🔴

The building shell separating the building from the external environment is critical for energy efficiency and user comfort design. The primary risk in building envelope design is that the insulation materials preferred for thermal insulation, the dry plants and plastic-based materials used in green roofs and walls, and the combustible properties of cladding materials contribute fuel to the fire and cause the fire to grow. In addition, vertical and window gaps caused by façade construction and ventilation are the primary risk that causes fire to spread indoors. Since the cladding panels, insulation elements, connections, and gaps between the building structure and the load-bearing system of the shell will pose problems for fire safety, solutions should be produced. Since the maintenance of the plants used in green roofs is important regarding fuel contribution in fire, the selected plants should be suitable for the region and easy to maintain. Criteria such as the gap size in the double-skin facade design, its total height, the characteristics of the windows used in adjacent spaces, and the automatic control of windows and ventilation ducts in case of fire and increasing the number of spandrel panels should be evaluated. For the danger of the glass surface on the facades exploding and falling with pressure, methods that choose falling or falling in the form of tiny pieces should be selected to fix the glass panel and the internal and external properties of the glass.

While taking natural air and light directly into the building from the facade is a passive design that covers all buildings, vertical gap designs that allow outdoor airflow and sunlight to be taken indoors at the desired level apply to green building designs. Vertical gaps, the distribution areas of the air flow entering the interior, have a chimney effect due to internal and external pressure differences. The primary risk for vertical indoor gaps is the spread of toxic gases from a fire that starts in a room due to the chimney effect. It is important for the fire safety design to prevent the spread of toxic gases from the fire into the spaces associated with vertical gaps and to extract gases through smoke extraction systems opened at the top of vertical gaps. In this direction, properly designed natural ventilation openings for the smoke exhaust system effectively stop the fire or keep smoke and other toxic gases at the upper levels of the gap to evacuate users and extinguish the fire. In addition, the smoke exhaust system design with natural ventilation as a design component should be considered an alternative to mechanical smoke exhaust systems. Vertical gap air inlets and outlets, ventilation openings of the spaces associated with the gap, and spatial dimensions affect fire growth through vertical gaps and should be analysed with traceable methods during the design phase.

The most critical risk arising from heating, cooling, and ventilation systems in buildings is spreading fire horizontally and vertically throughout the building through the gaps caused by these systems. In power generation systems, fire ignition is considered the primary risk due to combustible materials used in the systems and electrical faults. Electrical systems must be visible and labelled so that electrical and earthing faults can be seen and intervened. In addition, the system should be quickly shut down in case of any risk due to the possibility of explosion and ignition. Especially in photovoltaic panels, the necessary fire insulation of electrical cables and circuits and fire insulation between the photovoltaic panel and the building can prevent the spread of fire to the building. The areas that ensure the continuity of the air conditioning systems horizontally and vertically should not be connected with the spaces. In addition, air conditioning systems in each compartment created for building fire safety design should be independent or separated by fire dampers. In addition, air conditioning systems should be able to be switched off automatically to cut off the fresh air flow in case of fire.

4. CONCLUSIONS

Green buildings with a sustainable design approach that considers the present and future of people and the environment; while incorporating many important factors such as health, energy, cost, respect for the environment, and resource conservation, the issue of fire safety is not integrated from the beginning of the design and is seen as an obligation that only fulfils the requirements of the legislation. It is seen in the literature research and analyses that the approaches developed to ensure sustainability in green building designs with conscious and sensitive understandings pose risks in the context of fire safety. Although life safety is the primary purpose of fire safety legislation, the financial impact of fire on a business due to direct property damage or loss of production is also essential. By drawing attention to possible conflicts before the construction starts and making the necessary arrangements, time and economic waste can be avoided, and life safety can be ensured during the construction and use of the building.

In order to determine fire safety priorities for the building sector before the design starts, fire risks caused by green architectural features are analyzed in this study. Risk levels caused by green architectural design features are defined for fire safety design in green buildings. As a result of the analysis of the design components handled under 5 headings as land, building shell, materials, vertical internal gaps, building systems, and energy generating systems with their sub-headings, risk levels as high level, medium level, and low level were determined. Fire brigade access has been identified as the highest level of risk in landscape and building design in the area where the building is located. This risk shows that designers should create plans for extinguishing works as a priority in the land use process. Planning should be prioritized to allow the fire brigade to intervene at all points of the building, starting from access to the land.

Since the building shell is directly connected to the external environment, the fire that starts in the shell spreads very quickly due to wind and other airflow. For this reason, the shell design should be evaluated at the design stage as critical for fire safety design. Shell construction, building insulation, and ventilation design are the parameters that affect fire safety; flammable materials and low-strength building materials are the high-risk levels that fuel the fire and cause the fire to grow. In addition, the gaps between the double-skin facade and the curtain wall construction constitute the high-risk level that causes the fire to spread vertically and enter the building. The priority in shell design for the building sector should be to prefer non-combustible building materials and to take measures to prevent fire in vertical gaps. In green buildings, it should be evaluated that the shell design and the effective use of natural ventilation can be integrated for fire safety design and can be used to extract toxic gases.

While the internal gaps in traditional buildings are designed to carry mechanical and electrical systems and to illuminate rooms that do not receive direct light, the increase in electrical and mechanical systems in green buildings, the controlled use of natural ventilation and lighting by considering user comfort cause increase in the internal gaps of the building. The gaps in the building constitute the highest risk level for green building design as they cause the spread of smoke, flame, and other toxic gases between spaces in case of fire. With the highest risk level for fire spread between spaces, vertical gaps are critical areas that designers should consider for fire safety design. In addition, there are opportunities for smoke extraction through vertical gaps, delaying the entry of smoke into the spaces and providing opportunities for human evacuation.

Energy-generating systems and building heating, cooling, and ventilation are preferred for user comfort and energy efficiency in green buildings. Possible electrical faults in both energy generating systems and mechanical building heating, cooling, and ventilation systems have a high-risk level that causes the ignition of fire. Considering that electrical faults are as high as human error in fire starts, increasing electrical and mechanical systems in green buildings also increases the risk levels. Within the framework of the risks mentioned above, it is seen that it is essential that the design of air conditioning systems and energy-generating power supplies are fire-insulated for fire safety and that the systems are separated and intervenable.

In the event of a possible fire in green buildings with sustainable goals, life, and property safety and business continuity problems arise, and sustainable goals are destroyed. In line with these goals, this study has shown that the fire risks in green buildings, in which complex design components are formed, are higher than in traditional buildings. To ensure the safety of life and property and the continuation of the building service, in this study, as a result of the application of the determined risk levels to the appropriate design features before the building is constructed, all risk levels that may occur in the event of a possible fire will be defined and designed.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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