SOCIAL RESILIENCE TO HAZARDS: THE ROLE OF INSURANCE AND DISASTER RISK MANAGEMENT

Ljiljana POPOVIĆ

University of Novi Sad, Faculty of Technical Sciences

Abstract

This paper examines how disaster risk management (DRM) and insurance contribute to enhancing social resilience in the face of natural and human-induced hazards. It explores the structure and function of the disaster risk management cycle, emphasizing the importance of a proactive and integrated approach that includes prevention, mitigation, preparedness, response, and recovery. Special attention is given to the mechanisms of risk allocation, such as retention and transfer, and how these influence community resilience, particularly during catastrophic events. Insurance is analyzed not only as a financial instrument, but also as a social stabilizer that protects assets, enables risk sharing, and supports long-term recovery. Through the lens of social resilience, the paper illustrates how the alignment of public and private sector efforts in DRM and insurance fosters more adaptive, prepared, and secure societies. The analysis aims to support the implementation of comprehensive risk management strategies that reduce vulnerability and empower communities to withstand and recover from disasters more effectively.

Keywords: disaster risk management, prevention, mitigation, preparedness, insurance

1. SOCIAL VULNERABILITY IN THE CONTEXT OF CATASTROPHIC EVENTS

A wide range of academic literature that deals with the concept of vulnerability provides valuable insights into understanding how and why certain individuals, households, and social groups are disproportionately affected by extreme events and disasters. These sources help uncover the root mechanisms that explain this disproportionality and offer critical directions for evaluating exposure and adaptive capacity. Numerous vulnerability models further emphasize specific factors that influence the level of exposure and the ability to respond to disaster events (Bohle, 2001; Davidson, 1997; Bollin et al., 2003; Turner et al., 2003; Wisner et al., 2004; Birkmann and Bogardi, 2004; Cardona, 1999).

The PAR model (Pressure and Release Model), developed by Wisner et al. (2004), explicitly explains how "unsafe conditions" are transformed into disasters as a result of exposure to biophysical, social, political, and economic pressures. This model illustrates that vulnerability is deeply rooted in social structures and processes, and it highlights the causes of vulnerability, both dynamic pressures and root causes, which are often temporally or spatially distant from the specific site and moment of a disaster event.

The BBC model (Birkmann and Bogardi, 2004; Cardona, 1999 and 2001) was developed in response to some of the most frequently asked questions in disaster risk analysis: How can vulnerability be linked to human security and sustainable development? How can we create a holistic model to assess risks with catastrophic impacts and to guide efforts for environmental degradation measurement within the context of sustainability?

1.1. The PAR Model for Vulnerability Assessment

Vulnerability, in the context of the PAR model, originates from complex social processes and fundamental structural causes that may be spatially and temporally distant from the disaster itself. The central idea of the Pressure and Release (PAR) model is that a disaster represents the intersection of two opposing forces: on one side, the processes that generate vulnerability; and on the other, the presence of a hazardous event.

The model emphasizes that understanding disasters requires tracing the linkages between the physical impact of a hazard and the underlying social structures and processes that shape vulnerability. Vulnerability is understood through three sets of causal connections that link a disaster to specific processes affecting the exposed population (Figure 1).

- Root causes form a chain of interrelated, widespread, and deeply embedded processes within society and the global economy. These causes are:
- Spatially distant (originating from distant centers of political or economic power), and/or
- Temporally distant (emerging from the distant past), and/or
- Culturally embedded (rooted in societal ideologies, beliefs, norms, and relationships).

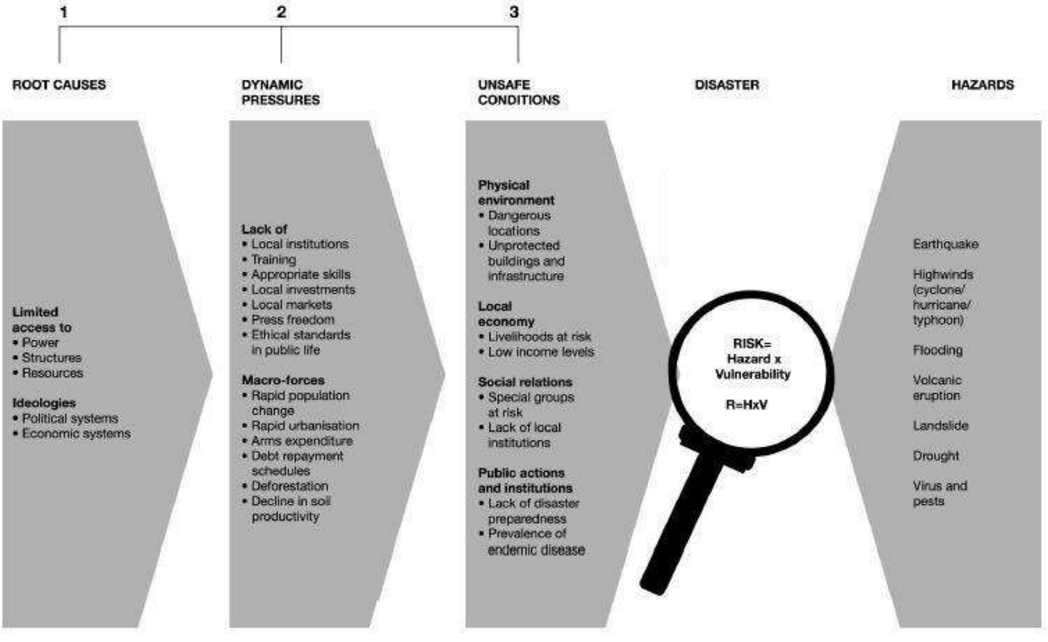

Figure 1 – Pressure and Release (PAR) model (Wisner et al., 2004)

The most significant root causes of vulnerability (which are often reproduced over time) include economic, demographic, and political processes. These processes influence how resources are allocated and distributed among different social groups. They depend on national and global economic structures, political systems, and the legal framework for enforcing rights. Root causes are also closely tied to the functioning (or dysfunction) of the state and to the nature of institutional control.

These root causes reflect the exercise and distribution of power in society. Marginalized populations, those who are economically excluded or who live in ecologically marginal environments (e.g., remote, arid or semi-arid regions, flood-prone coastal areas, or fragile forest ecosystems), are of little significance to those who hold political and economic power. This creates three often interconnected sources of vulnerability:

- If people only have access to fragile or insecure livelihoods and resources, their everyday activities are likely to generate higher levels of vulnerability.
- Their presence and needs are unlikely to be a priority in government-led disaster mitigation strategies.
- They are more likely to lose faith in both formal systems and their own indigenous coping mechanisms, eroding trust in local knowledge and self-protection strategies.

Dynamic pressures are social processes and institutional activities that translate the effects of root causes into immediate conditions of vulnerability. These are more contemporary or present-day manifestations of broader structural trends and include:

- Rapid urbanization,
- Rural-to-urban migration,
- Armed conflict and civil unrest,
- Foreign debt and structural adjustment programs,
- Environmental degradation (e.g., deforestation, soil erosion),
- Epidemics or pandemics.

Dynamic pressures serve as transmission channels, conveying root causes into unsafe conditions in space and time. They shape the landscape of everyday risk and are crucial in understanding how structural inequities translate into concrete vulnerabilities. It is important to note that dynamic pressures are not inherently "bad" but become sources of vulnerability in certain contexts, depending on governance, capacity, and institutional resilience.

Unsafe conditions are the most visible manifestations of vulnerability, representing specific situations in time and space where people are exposed to risk. These conditions are strongly influenced by a population's baseline wellbeing and vary significantly across regions, micro-regions, households, and individuals. To fully assess unsafe conditions, it is essential to consider access to both:

- Tangible resources (money, food stocks, housing, tools, agricultural assets), and
- Intangible resources (social networks, cultural knowledge, coping skills, awareness of assistance mechanisms).

Most commonly, reducing vulnerability is interpreted as reducing social poverty. Therefore, there must be a direct link between disaster preparedness, vulnerability reduction, and the development process, that is the improvement of people’s lives, wellbeing, and opportunities. This is clearly illustrated in the PAR model, which shows that vulnerability, emerging from unsafe conditions, intersects with a triggering hazard to produce a disaster.

1.2. BBC Model of Vulnerability Assessment

The BBC Model (Bogardi-Birkmann-Cardona Model) emphasizes that vulnerability analysis must go beyond the measurement of deficiencies or simple assessments of disaster impacts in the past. It calls for a more comprehensive and process-oriented perspective, wherein vulnerability is viewed as a dynamic phenomenon, shaped by the interaction between hazards, societal structures, and the environment.

The BBC model highlights the necessity of simultaneously analyzing vulnerability, coping capacity, and potential tools for vulnerability reduction. It argues that vulnerability should not be seen as an isolated factor, but rather as one that is inseparably linked to exposure, risk perception, and the broader development process.

In this model, vulnerability assessments consider specific hazard types, the exposed and affected populations, their economic systems, and the ecological conditions in which they live. These interdependencies are critical, as they determine the structure of risk and the outcome of any potential disaster (Figure 2).

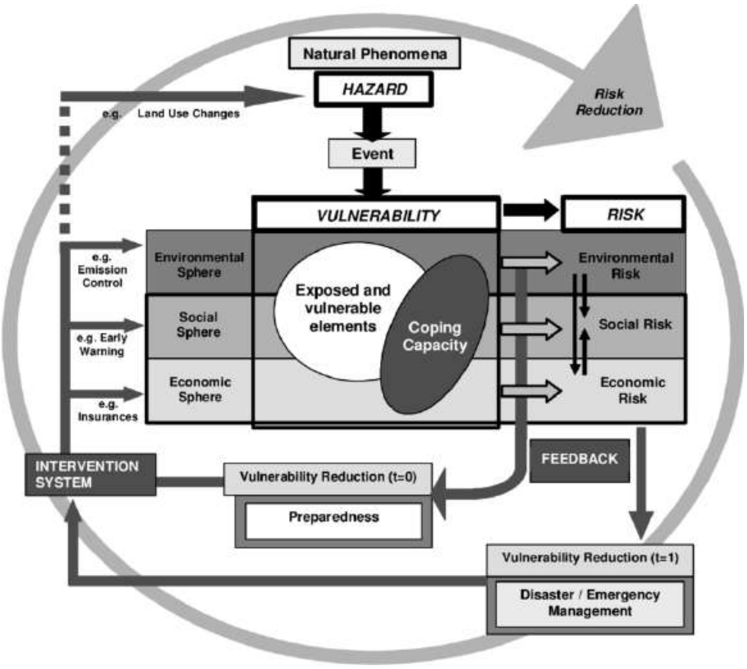

Figure 2 – BBC Model (Birkmann and Bogardi, 2004)

The BBC model defines three key dimensions within which vulnerability should be analyzed:

- Environmental Vulnerability – Refers to exposure to natural hazards and the physical fragility of systems and infrastructure. It includes:
  - Physical location (e.g. settlements in flood zones or landslide-prone areas),
  - The level of environmental degradation (e.g. deforestation, loss of wetlands),
  - Dependence on climate-sensitive resources (e.g. rain-fed agriculture).
- Social Vulnerability – Captures the sensitivity of specific social groups and their lack of access to resources, services, and information. It encompasses:
  - Poverty and inequality,
  - Exclusion from decision-making,
  - Lack of social cohesion or institutional support,
  - Education and awareness levels
- Economic Vulnerability – Describes dependency on unstable, low-income, or informal economic activities, often without savings or insurance. It involves:
  - Weak employment structures,
  - Undiversified income sources,
  - Limited access to financial services or credit.

These dimensions are structurally aligned with the three pillars of sustainable development: environment, society, and economy, and the BBC model connects them explicitly to disaster risk reduction frameworks.

The BBC model introduces a temporal dimension by distinguishing between:

- t = 0: The moment before a disaster occurs, when vulnerability reduction should take place.
- t = 1: The moment after the disaster begins, when emergency response and disaster management are activated.

This distinction underlines the model's argument that preparedness and vulnerability reduction must occur before the hazard manifests, not merely in the aftermath. Thus, emergency management is important at t = 1, but long-term resilience depends heavily on actions taken at t = 0.

The BBC model also stresses the role of organizational and institutional factors in shaping vulnerability:

- The strength of governance,
- Access to early warning systems,
- Presence of ethical standards in public administration,
- Availability of local institutions, investments, training, and knowledge.

It recognizes that the way power and resources are distributed affects both vulnerability and the capacity to cope with risks. In addition, it draws attention to how political decision-making processes can either reinforce or mitigate vulnerability, depending on the extent to which they integrate environmental and social concerns.

By linking sustainable development with vulnerability reduction, the BBC model urges for a shift toward proactive strategies. It encourages:

- Risk reduction strategies before hazards strike,
- Investment in preparedness and early warning,
- Integration of environmental protection and social justice in planning.

For example, the model highlights how investment in risk prevention and readiness has a much greater long-term effect than funding disaster relief and reconstruction after the fact.

Unlike models that focus narrowly on mortality or economic loss, the BBC model identifies diverse types of vulnerability: environmental, social, and economic—and insists that vulnerability should be addressed before a triggering event results in a disaster. These vulnerabilities are not only measurable but also actionable, especially when incorporated into national and local development policies.

Ultimately, the BBC model provides a framework for understanding vulnerability in the context of risk systems. It emphasizes that:

- Vulnerability must be reduced before the hazard manifests (t = 0),
- Interventions must be multi-dimensional, addressing all three pillars of sustainability,

- Risk reduction strategies should focus on systemic causes and not just symptoms,
- Policy decisions must treat vulnerability reduction as a development priority, not as an afterthought in disaster response.

By clearly identifying vulnerabilities, capacities, and pathways of impact, the BBC model guides institutions toward more effective and equitable disaster risk management strategies.

2. DISASTER RISK MANAGEMENT

2.1. The Disaster Risk Management Cycle

To reduce the impacts of catastrophic events on ecosystems and to increase the resilience of communities to such events, a fundamental paradigm shift is required — moving from a reactive model based on “disaster defense” to a proactive and systemic model of disaster risk management.

This shift emphasizes a holistic approach, which involves taking appropriate action before, during, and after a catastrophic event. Disasters are no longer seen solely as natural phenomena but as outcomes of intersecting factors: environmental, social, economic, and institutional.

According to Davis (1978), Hewitt (1983), and Cuny (1983), disaster risk management must be planned and continuous, rather than reactive and event-driven. A typical disaster risk management cycle illustrates the interconnection of all key components.

A comprehensive disaster risk management system consists of four main components:

- Prevention and mitigation
- Preparedness
- Response
- Recovery

Each of these phases is essential and interconnected, forming a continuous cycle rather than a linear sequence.

2.1.1. Prevention

One of the most important methods of risk management is prevention. The term originates from the Latin word praevenire, meaning “to come before” or “to anticipate,” and encompasses ideas such as avoiding, intercepting, or averting undesired outcomes.

In modern risk management, prevention refers to a set of activities aimed at eliminating or reducing the likelihood of a harmful event occurring. In practical terms, it involves acting on the potential source of danger through the use of technical solutions and protective systems.

Preventive measures are designed either to remove the root cause of possible damage or to reduce the probability of the hazard occurring. For example:

- The likelihood of flooding can be reduced by constructing levees or embankments.
- The risk of fire can be minimized by safe storage of flammable materials.
- Earthquake damage can be reduced by designing buildings to comply with seismic safety standards.

Prevention is therefore about acting early, well before a hazard materializes. It requires both technical understanding and strategic foresight.

While prevention reduces the probability of a disaster occurring, it does not guarantee that damages will not occur. For this reason, mitigation measures are necessary to minimize the severity of impacts when a disaster does happen.

Mitigation refers to actions taken in advance of a potential event, with the goal of limiting its destructive consequences to an acceptable level. In disaster risk management, mitigation can be defined as the implementation of measures aimed at reducing the intensity and scope of adverse outcomes from hazard events.

Mitigation measures are generally divided into two main categories:

- Structural mitigation measures
- Non-structural mitigation measures

Structural mitigation involves the use of construction, engineering, and physical infrastructure to reduce risk. These include:

- Flood control dams
- Earthquake-resistant buildings
- Storm drainage systems
- Fire-resistant materials

These measures aim to physically alter the environment or infrastructure to resist or absorb the effects of disasters. They are often perceived as “human efforts to control nature.”

Non-structural mitigation includes strategies that do not require construction but instead involve modifying human behavior or natural processes to reduce risk. Examples include:

- Land-use zoning and restrictions in hazard-prone areas
- Public education and awareness campaigns
- Insurance programs and financial risk-sharing mechanisms
- Environmental restoration to stabilize natural buffers (e.g., wetlands, forests)

These measures are often more cost-effective and easier to implement, especially in communities with limited financial or technological resources. They are typically viewed as “humans adapting to nature.”

2.1.2. Preparedness

Preparedness is one of the proactive components of disaster risk management, referring to a set of actions undertaken before the occurrence of a hazardous event. The main goal is to create the necessary conditions for an effective response and for rapid recovery from the consequences of a disaster. In this sense, preparedness eliminates the need for last-minute reactions by ensuring that all stakeholders know what to do in advance.

Preparedness minimizes the negative effects of hazards by implementing precautionary measures that enable a timely, adequate, and efficient organization and implementation of activities during and after a catastrophic event — namely, during the response and recovery phases.

Preparedness measures can be categorized based on the type of recipient into two main groups:

Institutional Preparedness (Government and Authorities)

This includes activities carried out by public institutions such as civil protection agencies, local and national governments, emergency services, public health authorities, and crisis management teams. Key preparedness activities in this group include:

- Risk mapping and hazard assessments
- Development of emergency response plans
- Coordination mechanisms between sectors and agencies
- Training and simulation exercises for emergency responders

Institutional preparedness is generally defined and operationalized through formal contingency plans, standard operating procedures (SOPs), and regular capacity-building exercises.

Community and Individual Preparedness

This group includes physical and legal persons (i.e., households, businesses, NGOs) within the local community. Key activities involve:

- Public education on disaster awareness and self-protection
- Distribution of guidelines for emergency behavior (e.g., evacuation routes, emergency kits)
- Engagement of civil society in preparedness and response planning

The goal is to empower the general population with knowledge and skills to act appropriately in emergencies, reducing dependence on institutional aid and enhancing community resilience.

2.1.3. Response

Response refers to the set of immediate actions taken to manage the direct effects of a disaster, with the primary goals of:

- Saving lives
- Preventing injuries
- Protecting property and the environment

These actions are implemented just before, during, and immediately after a catastrophic event. The response phase is often the most complex and time-sensitive component of disaster risk management. It is carried out under intense stress, time pressure, and frequently with limited access to reliable information.

The response process begins the moment the hazard becomes imminent and continues until the emergency situation is under control or the state of emergency is lifted.

Examples of response activities include:

- Activation of emergency services (firefighters, rescue teams, ambulance services)
- Early warnings and evacuations
- Emergency medical interventions and triage
- Temporary shelters and food distribution
- Real-time coordination between agencies and decision-makers

It is important to note that both natural hazards and man-made accidents can trigger emergency situations. Whether or not such events escalate into full-scale disasters often depends on the effectiveness of the response.

2.1.4. Recovery

The recovery phase is the final component of the disaster risk management cycle. It refers to the period following a catastrophic event during which systems, services, infrastructure, and communities are restored, repaired, or rebuilt. This phase aims not only to return to the pre-disaster state but also, where possible, to reduce the risk of similar disasters in the future by implementing improved, more resilient solutions.

Recovery activities begin immediately after the response phase ends, although some may overlap with ongoing emergency interventions. Recovery can be divided into two types based on its time frame and objectives: short-term and long-term recovery.

Short-Term Recovery (Rehabilitation)

Short-term recovery includes activities that begin while emergency interventions are still ongoing. These actions aim to:

- Restore essential services (e.g. electricity, water, transportation)
- Provide temporary housing and basic needs
- Ensure access to healthcare and education
- Support psychological and social stabilization

The focus of this phase is stabilization — ensuring that life can resume in a basic and safe form while preparing for more comprehensive recovery activities.

Long-Term Recovery (Reconstruction)

Long-term recovery, or reconstruction, refers to the comprehensive rebuilding of infrastructure, institutions, and livelihoods. This stage marks the point where the affected community begins to rebuild itself in a strategic and often transformative way.

- Reconstructing permanent housing, schools, and hospitals
- Reviving local economies and employment

- Improving governance and social cohesion
- Integrating disaster risk reduction into rebuilding plans

Recovery as an Opportunity for Development

A disaster, despite its devastating effects, often creates a unique opportunity for positive change. The recovery phase is not just about restoring what was lost — it is about building back better. In this sense, recovery becomes a development opportunity.

This phase allows decision-makers and communities to:

- Rethink previous vulnerabilities
- Address structural inequalities
- Invest in long-term resilience

Mitigation measures that were previously deferred due to high costs or political constraints may now receive greater support, funding, and social acceptance. For example:

- Flood-prone communities may relocate to safer areas
- New infrastructure may be designed to higher standards
- Early warning systems may be upgraded

3. RISK ALLOCATION

Risk allocation is a key aspect of risk management that determines who bears the financial consequences of a given risk. One of the most common methods of risk management is risk retention. Individuals are continuously exposed to a wide range of risks, and in many cases, no specific action is taken to address them.

3.1. Risk Retention

Risk retention occurs when an individual or organization accepts the financial consequences of a potential loss. This can happen either consciously or unconsciously:

- Conscious risk retention occurs when a risk is properly assessed and a decision is made not to transfer or mitigate it. This approach is typically used when:
  - The potential loss is relatively small
  - No better alternatives are available
  - The cost of risk transfer (e.g. insurance) exceeds the expected benefit
- Unconscious risk retention happens when the risk has not been assessed or even recognized. In such cases, individuals or organizations retain the risk without being aware that they are doing so. This often happens when the risk cannot be avoided, transferred, or mitigated.

In many situations, retaining risk is the most appropriate solution, especially when the expected loss is minor or infrequent. Retained risks are typically those that would not result in severe financial harm.

3.2. Risk Transfer

When the expected consequences of a risk are significant, the preferred method is risk transfer. This involves shifting the burden of financial loss to another party that is more willing or better equipped to handle it.

There are several ways to transfer risk:

- Insurance is the most widely used method. By paying a premium, the insured party receives a contractual guarantee that, in the event of a loss, the insurer will compensate the damage up to a defined limit.
- Contracts may contain risk-sharing clauses, such as in construction, finance, or supply chain agreements. These clauses clearly define which party is responsible for specific risks.
- Financial instruments, such as derivatives, allow the transfer or hedging of market-related risks. Examples include futures, options, and swaps.

The choice between retaining or transferring risk depends largely on the intensity (severity) and frequency of the risk.

Risk management techniques vary depending on the nature and intensity of the risk:

- Low to medium intensity risks are often addressed through preventive and mitigation measures. These are cost-effective and adequate when potential damages are manageable.
- High-intensity or catastrophic risks, which could result in major losses, generally require risk transfer mechanisms such as insurance or financial reinsurance.

Risk transfer mechanisms can be broadly categorized into ex-ante and ex-post strategies.

Ex-ante risk transfer refers to measures and instruments arranged before a disaster strikes, such as insurance and contingent credit lines. These mechanisms provide rapid liquidity and financial protection, ensuring that resources are available when needed most.

On the other hand, ex-post mechanisms are activated only after a disaster occurs and include donor assistance, budget reallocation, and emergency loans. While ex-post measures often play a critical role in recovery, they are typically slower and less predictable than ex-ante arrangements.

An effective disaster risk financing strategy usually combines both ex-ante and ex-post instruments to build financial resilience, ensure response readiness, and reduce the long-term economic impact of disasters (Figure 3).

Figure 3 – Integrated approach to DRRC (GIZ & MCII., 2017)

4. INSURANCE AS A FINANCIAL RISK MANAGEMENT MECHANISM

Insurance is a specialized domain within risk management that focuses on analyzing the consequences of risk realization, the economic impacts associated with these events, and the available mechanisms for mitigating or preventing potential losses.

At its core, insurance is both a scientific discipline and a financial institution that compensates for damage to property or persons resulting from the realization of risks such as natural disasters or accidents. More broadly, insurance represents a collective pooling of individuals or entities exposed to similar risks, with the purpose of sharing the economic consequences of a loss that is likely to affect at least one member of the group within a given timeframe.

The fundamental principle underlying insurance is risk - the uncertainty regarding future loss or harm, whether related to property (economic loss) or to persons (health or life, i.e., moral loss).

Insurance operates on the basis of:

- Mutuality – the shared assumption of risk
- Solidarity – the collective support of all policyholders

- Actuarial fairness – distributing risk across large groups based on statistical modeling

This means that losses arising from natural or accidental events within a given risk group are not borne by the individual alone, but are shared among all participants who are exposed to similar threats. In actuarial terms, this is called risk equalization and atomization, which allows the economic burden of losses to be distributed across many policyholders, making it more manageable.

Insurance is not only a risk transfer mechanism, it is also a commercial activity whose main objective is to provide services in exchange for premiums, with the goal of generating profit while maintaining financial stability.

4.1. Core Functions of Insurance

According to the Association of British Insurers (ABI, 2005a, 2005b), insurance performs three core functions in society:

1. Protection of Property (Asset Preservation)

This is the primary function of insurance. It can be realized in two ways:

- Direct protection (preventive function): Involves measures aimed at preventing or reducing the occurrence of damage. Insurers often support safety initiatives, risk assessments, and preventive technologies to reduce the likelihood of claims.
- Indirect protection (compensatory function): When a loss does occur, insurance provides financial compensation using funds collected from policyholders' premiums. This function allows for the economic recovery of individuals, businesses, and communities.

2. Financial Function

The financial role of insurance stems from the fact that premiums are paid in advance, while compensation for losses is paid gradually as claims arise throughout the policy period. During this time, the accumulated premiums are:

- Invested in various financial instruments
- Used to build technical reserves
- Managed to generate profits, which sustain the solvency of the insurance company and support long-term claims obligations

This function highlights the role of insurance companies as institutional investors in the financial market.

3. Social Function

Insurance also fulfills a socially protective role:

- Directly, through life and health insurance, by providing income or coverage in the event of death, illness, or disability.

- Indirectly, through property insurance, by preserving economic assets and preventing individuals and families from falling into poverty after catastrophic losses.

Through this function, insurance contributes to social stability, economic continuity, and poverty reduction, particularly in vulnerable populations.

5. CONCLUSION

In the face of escalating natural and human-induced hazards, the importance of comprehensive disaster risk management (DRM) and insurance mechanisms has become increasingly evident. This paper has highlighted how proactive approaches by integrating prevention, mitigation, preparedness, response, and recovery, enhance the resilience of communities and reduce vulnerability to disasters. Through the analysis of key vulnerability models (PAR and BBC), it is clear that social, economic, and environmental factors interact in complex ways, often exacerbated by structural inequalities and institutional weaknesses.

Risk allocation remains a central pillar of DRM. The distinction between risk retention and risk transfer, including ex-ante and ex-post financial instruments, underscores the need for strategic, layered financial planning. Insurance, in particular, plays a dual role, both as a preventive tool that incentivizes risk reduction and as a corrective mechanism that enables recovery after a disaster. Its social function, in terms of protecting households and stabilizing livelihoods, is especially critical in contexts where institutional safety nets are weak or absent.

Ultimately, building resilience is not only a technical endeavor but a social and political one. It requires collaboration between public and private sectors, active community engagement, and the alignment of risk reduction strategies with sustainable development goals. By strengthening institutional capacity, promoting inclusive risk financing frameworks, and embedding insurance into DRM policy, societies can become more adaptive, equitable, and prepared for future shocks. The integration of these mechanisms supports not only faster recovery but also long-term transformation toward greater climate and disaster resilience.

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FIRE SAFETY OF ENERGY EFFICIENT BUILDINGS

Meri CVETKOVSKA[1], Mirjana LABAN[2]

[1]Full prof. Dr, Ss. Cyril and Methodius University in Skopje, Faculty of Civil Engineering, North Macedonia, cvetkovska@gf.ukim.edu.mk

[2] Full Prof. Dr, Faculty of Tecnical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, Serbia, mlaban@uns.ac.rs

Abstract

This lecture presents the numerically achieved results for the fire resistance of several types of floor structures which are mostly used in our residential and rural buildings and in same time fulfill the energy efficient criteria, as: semi-prefabricated reinforced concrete slabs system FERT and STIRODOM (with infill of extruded polystyrene -XPS), timber-concrete composite floor structure and traditional timber floor structure. The solid RC slab was analyzed only for comparison. Using the computer programs SAFIR and FIRE, the effect of the intensity of the permanent and variable actions and the effect of the thermal isolation on the fire resistance of simply supported slabs were analyzed. The fire resistance was defined with respect to the criteria of usability of the structures in fire conditions, according to Eurocodes.

Fire spread through the facades is widely recognized as one of the fastest pathways of fire spreading in the buildings. Numerical simulation of external fire on a facade was done. The fire resistance of RC wall, with and without thermal insulation, was defined and the negative effect of the extruded polystyrene, as external insulation, in comparison with the rock wool insulation is presented.

Keywords: *energy efficiency, heat transfer, temperature, fire resistance, thermal isolation, floor structures, simply supported slabs, building facade*

1. INTRODUCTION

Nowadays the growing focus on “sustainable” buildings results in an increased thickness of building insulation and an extended use of combustible insulation materials e.g. foam plastics or cellulose fibers (Krause et al., 2012, Meacham et al., 2012, Tidwell and Murphy, 2010). Moreover, it has become more common to apply the insulation to the external wall surface instead of in the wall cavity, and as part of the floor structure used for ceiling or floor over the unheated basements. The tendency to use thicker layers of insulation and a wider use of combustible insulation materials is identified to pose a potential risk to fire safety of buildings. Controlling the fire spread in a building can increase the time available for occupant evacuation, decrease the fire losses and help the fire fighters in evacuating occupants and efficiently fighting the fire as well as increase the time available to reduce the fire spread to higher floors and adjacent buildings.

The fire resistance of structural elements is defined with respect to the criteria of usability of the structures in fire conditions, according to Eurocodes (MKC EN 1991-1-2, 2004, MKC EN 1995-1-2, 2004) and the standards in force. The criterion Integrity (E) expresses the ability of the separating element of the building construction, when exposed to fire on one side, to prevent the passage through it of flames and hot gases and to prevent the occurrence of flames on the unexposed side.

The criterion Insulation (I) expresses the ability of the separating element of the building construction when exposed to fire on one side, to restrict the temperature rise of the unexposed face below specified levels and the criterion Load bearing function (R) expresses the ability of the structure or the member to sustain specified actions during the relevant fire, according to defined criteria.

Criterion “I” may be assumed to be satisfied where the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K.

Floor structures, as horizontal elements, have a very important role in providing bearing capacity, usability and stability of the building as a whole. Their proper selection and design, when they are exposed to different types of loads (mainly: permanent and variable), should provide stable and safe structure during the exploitation period. In case of fire floor structures do not have only load bearing function. In most cases they are used as elements for separating the fire compartment. Where compartmentation is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure. This shall ensure, where relevant, that integrity failure does not occur, insulation failure does not occur, thermal radiation from the unexposed side is limited.

Does the floor structure meet the required fire resistance criteria mainly depends on: mechanical and thermal characteristics of the materials used for the construction; initial loading level; support conditions; dimensions of the cross section; steel ratio; concrete cover thickness and fire scenario.

In most European countries only a reaction to fire class of the façade constructions is required and the structural fire safety and fire resistance of the load bearing elements is not taken under consideration. The heat exposure from the diffusion gas burner used in the Single Burning Item (SBI) test is simulating a burning waste basket. Several studies have shown that results from the SBI test does not reflect how a building product will perform in a real fire, especially regarding the fire spread. In fact, when the SBI method was developed it was concluded that the method gives insufficiently reproducible results for most of the products. Especially for high rise buildings it is important to assess the complete construction of façade insulation systems, and not only the reaction to fire performance of the single components. In several EU countries a national large-scale façade test must be passed. Those tests are more realistic compared to the SBI test since heat exposure, size and spread of the flames in the large-scale tests are closer to the end-use condition.

In order to acknowledge the fire properties of a specific insulation product and give products with a low combustibility an advantage over products with a high combustibility, a more gradual approach is needed (i.e. combining combustible insulation materials with a protective layer). Based on the risk class of the building and the reaction to fire of the insulation product in use, an appropriate fire protection measure should be determined. For non-combustible insulation products no protective measures need to be specified. In that case, the reaction to fire performance for the construction as a whole is considered sufficient.

This lecture presents the numerically achieved results for the fire resistance of few types of energy efficient floor structures, as timber-concrete composite floor structure TCCFS, traditional timber floor structure TFS, for two different fire scenarios, as well as of semi-prefabricated reinforced concrete slabs system FERT and STIRODOM (with infill of extruded polystyrene-XPS) exposed to ISO 834 standard fire from the bottom side. Fire resistance of reinforced concrete facade wall with different types of thermal insulation from the external side is defined too, and the results are presented.

2. FIRE RESISTANCE OF TIMBER BASED FLOOR STRUCTURES

The timber floor is widely used in traditional and rural buildings, but the high combustibility of the wood results in low fire resistance of this type of floors. Wood can be protected by fire protective claddings, other protection materials or by other structural members and nowadays a special attention is paid to this problem. One of the possible solutions for increasing the fire resistance of wooden floor structures is the composite timber-concrete floor assembly made of timber girders and reinforced concrete slab, while the cavities are field with mineral or rock wool.

The effect of the intensity of the permanent actions and the effect of the position of the ISO 834 standard fire on the fire resistance of the two types of simply supported floor structures were analyzed by using the software SAFIR (2014), based on finite element method. The fire resistance was defined with respect to the load bearing criteria of the structure in fire conditions, according to EN 1995-1-2 (2004).

The cross sections and the dimensions of the two different types of simply supported floor structures with span L=5m were defined according to the current standards and are presented on Figure 1. Material properties at room temperatures are given in Table 1.

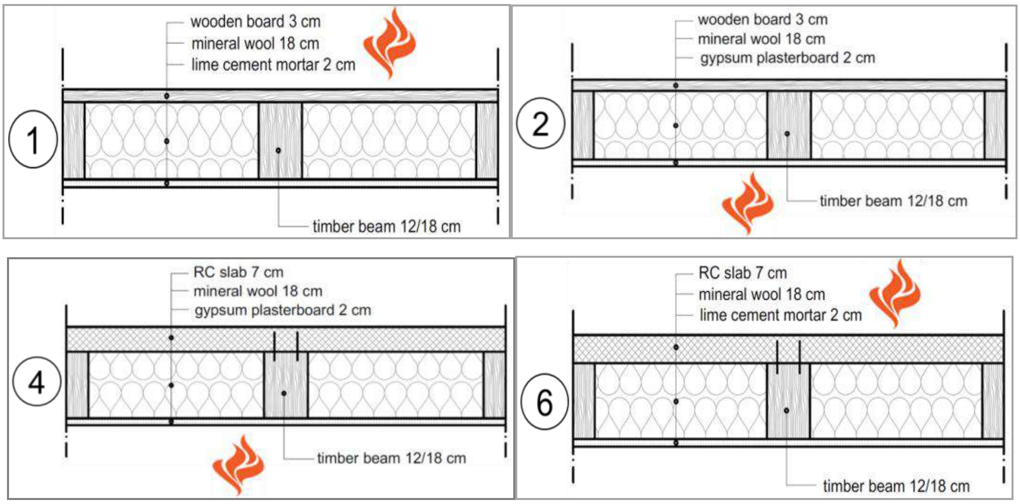

Figure 1 - The cross sections and the dimensions of the two different types of simply supported floor structures with specified position of the fire action

Table 1- Material properties of composite materials at room temperatures

Material properties	dimens.	Concrete	Wood	Gypsum	Mortar	Mineral wool
specific mass	kg/m^3	2400	450	900	1850	150
water percentage	%	8	4	4	8	2
convection coeff. on hot side	W/m^{2}K	25	25	25	25	25
convection coeff. on cold side	W/m^{2}K	9	9	9	9	9
relative emissivity	-	0,8	0,8	0,85	0,8	0,85
specific heat	J/kgK	900*	1530*	1090	400	150
thermal conductivity	W/mK	1,6*	0,12*	0,21	0,87	0,035

* The values for the specific heat and the thermal conductivity of concrete and wood are temperature dependent and only the initial values are given (T=20°C). Reductions of the values at higher temperatures are as it is recommended in EN 1992-1-2 and EN 1995-1-2.

The temperature dependent physical and mechanical properties of the siliceous aggregate concrete (compressive strength f_c=30Mpa) and the reinforcement (yield strength f_y=400Mpa) were assumed according to EN 1992-1-2 (2004). For standard fire exposure, values of thermal conductivity, specific heat and the ratio of density of soft wood were taken as given in EN 1995-1-2. The thermal conductivity values of the char layer are apparent values rather than measured values of charcoal, in order to take into account increased heat transfer due to shrinkage cracks above 500°C and the consumption of the char layer at about 1000°C (Figure 2). Cracks in the charcoal increase heat transfer due to radiation and convection. The computer program SAFIR (2014) does not take into account these effects.

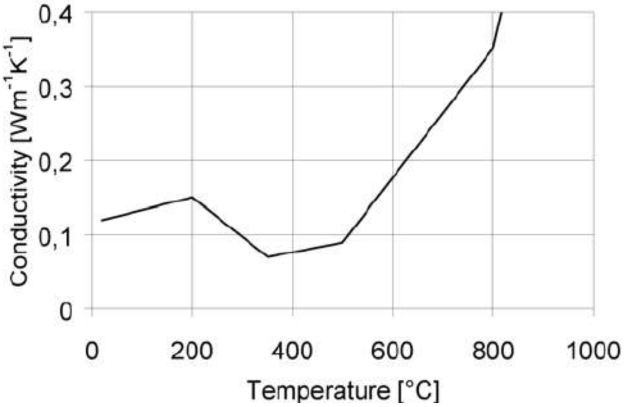

Figure 2 - Temperature-thermal conductivity relationship for wood and the char layer, according to EN 1995-1-2

Each type of floor structure was analyzed for two different types of ceiling: lime cement mortar 2cm or gypsum plasterboard 2cm, and for two different positions of the fire action, at the top and at the bottom side of the floor:

- Case 1: TFS with ceiling made of lime cement mortar, fire at the top side
- Case 2: TFS with ceiling made of gypsum plasterboard, fire at the bottom side
- Case 3: TFS with ceiling made of lime cement mortar, fire at the bottom side
- Case 4: TCCFS with ceiling of gypsum plasterboard, fire at the bottom side
- Case 5: TCCFS with ceiling made of lime cement mortar, fire at the bottom side
- Case 6: TCCFS with ceiling made of lime cement mortar, fire at the top side.

Numerically achieved results for the temperature distribution in the cross section of timber-concrete composite floor structure with gypsum plasterboard ceiling, for different position of the fire, are presented on Figure 3.

Numerically achieved results for the fire resistance of the two types of floors, for all 6 cases and different load coefficients, are presented on Figure 4 and Figure 5.

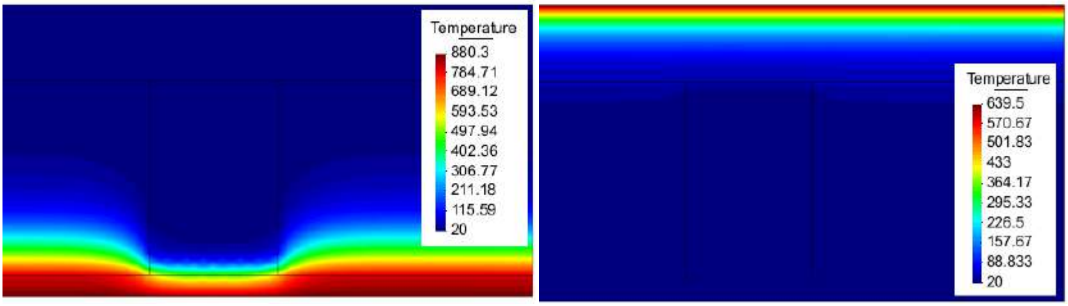

Figure 3 - Temperature distribution in the cross section of timber-concrete composite floor structure with gypsum plasterboard ceiling, at the moment of failure (q_{fi}/q_u= 0.8)

a) case 4-fire from the bottom side, t=2410 sec.; b) case 6-fire from the top side, t=1080 sec.

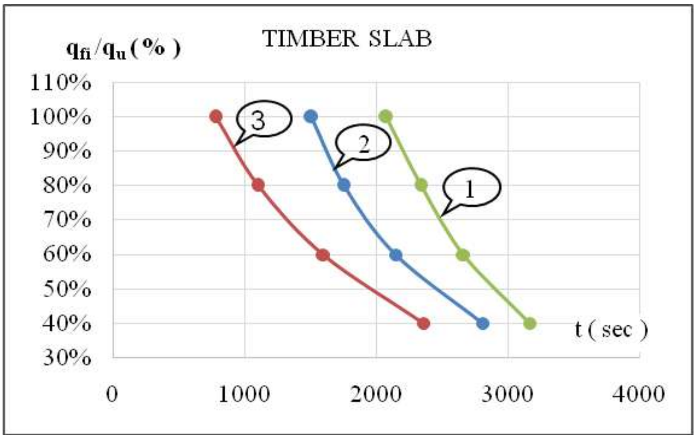

Figure 4 - The effect of the intensity of the permanent action and the position of the ISO 834 standard fire on the fire resistance of the simply supported timber floor structure

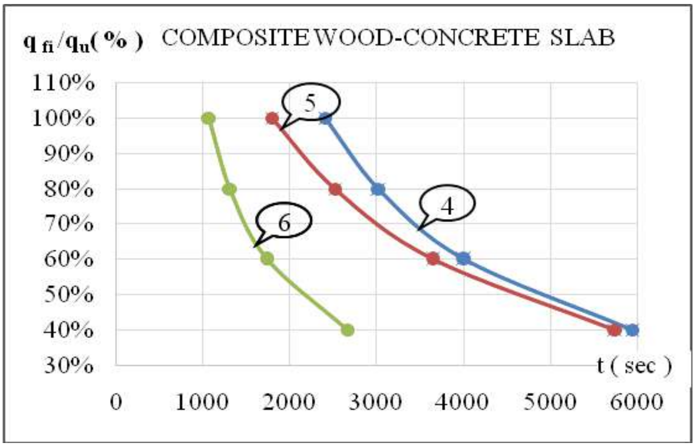

Figure 5 - The effect of the intensity of the permanent action and the position of the ISO 834 standard fire on the fire resistance of simply supported wood-concrete composite floor structure

The analysis presented in this paper show that from all six cases, the timber-concrete composite floor structure with ceiling made of gypsum plasterboard and exposed to fire from the bottom side has the best performance. The gypsum plasterboard ceiling and the rock wool infill have an insulating function and provide lower temperatures in the cross section of the floor assembly (Figure 3a). When the fire is from the top side of the thin concrete slab (d=7cm), in short time period the temperature penetrates dipper into the concrete slab (Figure 3b), the slab loses the bearing capacity and becomes a dead load for the timber girder, therefore the whole structure collapses earlier than in previous case. The additional reason for the failure is the compression stress in the concrete slab caused by the non-uniform temperature distribution in the cross section. When the floor structure is exposed to fire from the top, the upper side of the concrete slab becomes hotter than the bottom side and tends to expand more. The free thermal expansion is restricted by the linear strain distribution in the cross section of the slab and results in additional compression in the concrete slab and tension in the timber beam. When the fire is from the bottom side of the floor structure the effect of the non-linear temperature gradient is opposite, the positive moment at the mid-span is decreased and this effect increases the fire resistance of the simply supported floor structure.

When the floor structure is without ceiling made of gypsum plasterboard and rock wool infill, the timber beam and the concrete slab are directly exposed to the flames, the temperatures in the cross section are higher than in other cases and the fire resistance has the lowest value (Figure 6).

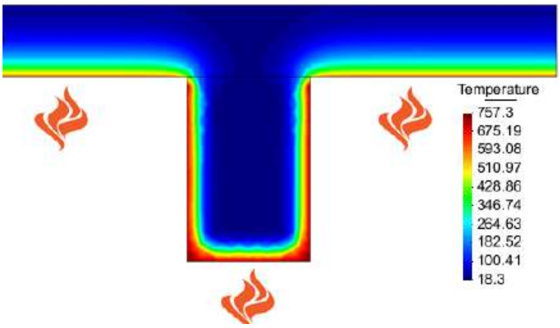

Figure 6. Temperature distribution in the cross section of timber-concrete composite floor structure without gypsum plasterboard ceiling, at the moment of failure ($q_{fi}/q_u = 0.8$), t=924 sec

When the load coefficient q_{fi}/q_u is increased (q_{fi} is the permanent action in fire condition and q_u is the ultimate load of the structure at ambient temperature), the fire resistance is decreased, but not proportionaly to the value of the load coefficient and this effect is mostly stressed in case 5. The timber floor structure (case 1, 2 and 3) has much lower fire resistance than the timber-concrete composite floor structure. It is more expressed when the load coefficient q_{fi}/q_u has expected values (less than 0.5). When fire is from the top side the char layer protects the timber girder from burning (low value of the thermal conductivity, Figure 2) and the girder keeps his original dimensions for a longer period than in case when the fire is from the bottom side.

For expected values of the load coefficient (q_{fi}/q_u less than 0.5) and for the same fire scenario, the fire resistance of the timber concrete composite floor structure is almost twice higher than the fire resistance of the timber floor structure.

3. FIRE RESISTANCE OF SEMI-PREFABRICATED FLOOR STRUCTURES

The fire resistance of three types of enrgy efficient floor structures that are mostly used in our buildings are analysed: semi-prefabricated reinforced concrete slabs system FERT and STIRODOM, as well as solid RC slab, for comparison (Figure 7). All three types of slabs were analysed as simply supported slabs L=6m and were exposed to ISO standard fire from the bottom side, as most critical fire scenario. The RC slabs and the slabs system STIRODOM were constructed with and without thermal insolation at the bottom side od the slabs and the positive effect of the thermal insulation was confirmed.

The computer programs SAFIR (2014) and FIRE (Cvetkovska, 2002) based on Finite Element Method, were used for the fire resistance analysis. Both programs are capable of conducting the nonlinear and transient heat flow analysis and nonlinear stress-strain response associated with fire. The temperature dependent physical and mechanical properties of the siliceous aggregate concrete (compressive strength fc=30Mpa) and the reinforcement (yield strength fy=400Mpa) were assumed according to EC2, part 1-2. Phusical properties of other materials at ambient temperature were taken according to the values provided by the producers and are given in Table 2.

Table 2. Material properties of composite materials at room temperatures

Properties/material		brick	Plasterboard	EPS	Concrete	Reinforcement
density	kg/m^3	1500	1000	30	2400	7800
thermal conductivity	W/mK	0.80	0.21	0.035	2.0	54
specific heat	J/kgK	920	1090	1450	960	440
Surface emissivity		0.93	0.85	0.90	0.92	0.69

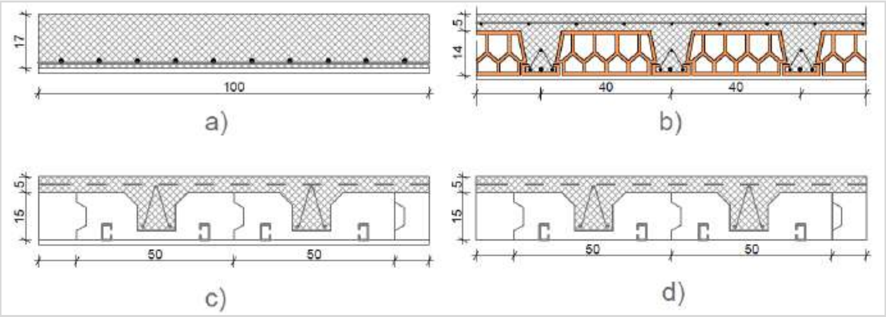

Figure 7 - Different types of floor structures: a) RC slab; b) slab system FERT; c) slab system STIRODOM with plasterboard as thermal insulation; d) slab system STIRODOM

As first case study the criterion **Load bearing function (R)** was analyzed. For all types of floor structures the design loads (permanent and variable) at ambient temperatures were assumed to be the loads that cause vertical deformation equal to L/250 (MKC EN 1991-1-2, 2004). These loads were considerably lower than the ultimate loads. For the selected types of floor structures the fire resistance in time domain is presented in Figure 8.

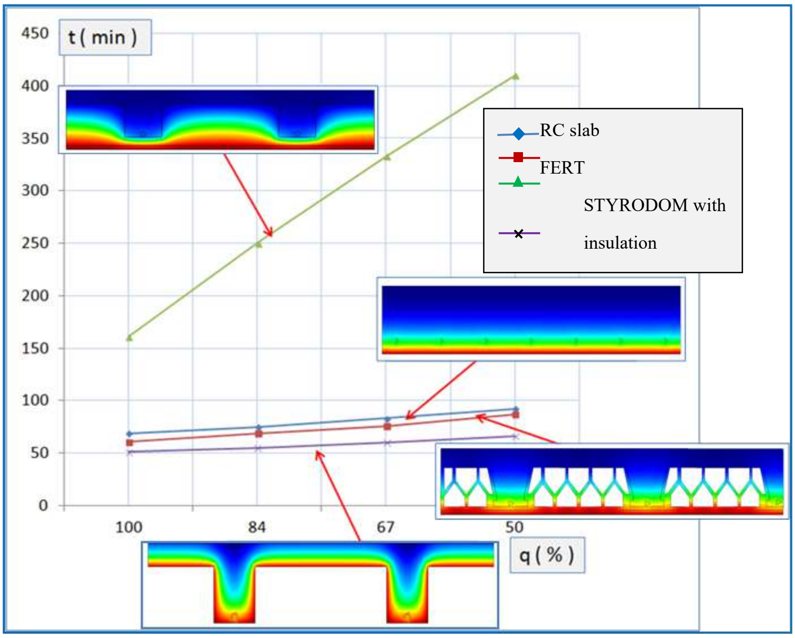

Figure 8- Fire resistance of different types of simply supported floor structures, as function of the applied loads expressed as percentage of the design loads that cause deflections L/250

The design loads that at ambient temperatures cause vertical deformation equal to L/250 are taken as 100%. All other loads are given as a percentage of these limited design loads (84%, 67% and 50%). Differences in the fire resistance of the certain types of floor structures are not significant except for the slab system STYRODOM with ceiling of plasterboard. This type of floor structure is more resistant to the effects of temperature and the fire resistance is much higher than for the other types of floor structures. The same structure, but without plasterboard at the bottom (ceiling) side (only thin plaster layer), has the lowest fire resistance. The reason for that is the melting of the infill of extruded polystyrene-XPS caused by temperatures over T=240°C. At temperatures T=450-500°C the infill is completely burned and the temperatures in the cross section of the slab are much higher than in other three cases. Consequently, the deflection rapidly increases much more over the limited value L/30.

As a second case study the **Insulation criterion (I)** was analysed. For fulfillment of this criterion the average temperature rise over the whole of the non-exposed surface was limited to 140°C, that means the temperature was limited to 160°C (the ambient temperature before action of fire was 20°C) and the maximum temperature at any point of that surface was limited to 200ºC. In case of slab system STYRODOM without plasterboard at the bottom side the temperatures in the cross section were highest (Figure 9). The reason for that was the melting of the infill of extruded polystyrene-XPS caused by temperatures over T=240ºC. The speed of melting was 4-6,4 mm/sec. In case when thermal insulation of 1.5cm plasterboard was applied at the bottom side of the slab, the moment of melting was posponed and temperatures of the cross sectin were less then in case without plasterboard (Figure 10).

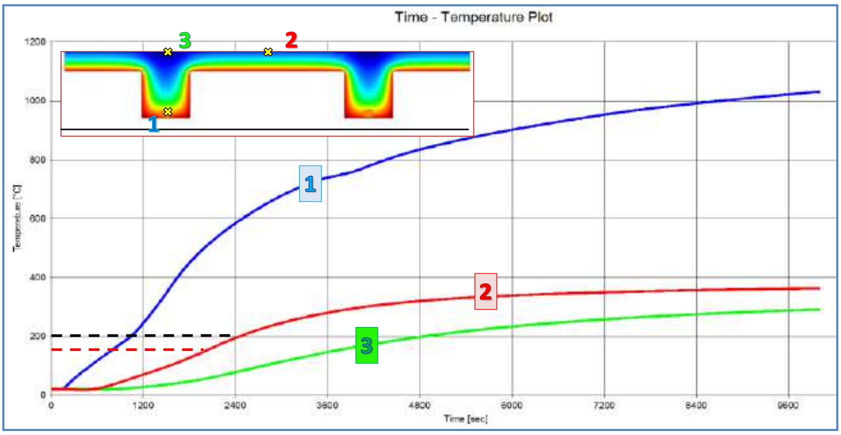

Figure 9 - Temperatures in characteristic points of the cross section of slab system STYRODOM without plasterboard at the bottom side

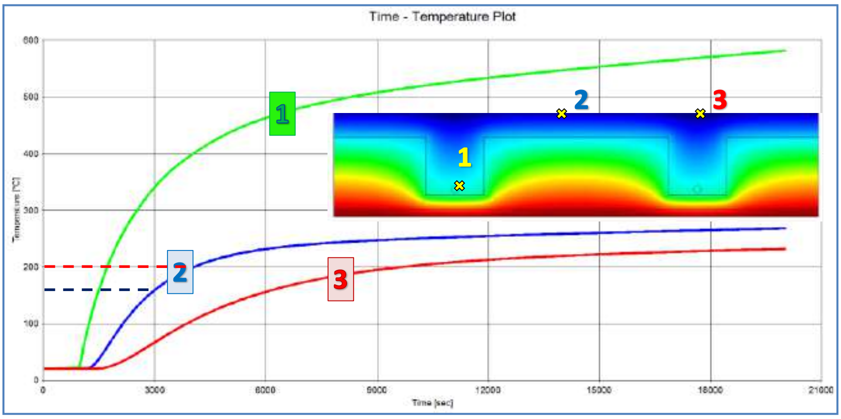

Figure 10 - Temperatures in characteristic points of the cross section of slab system STYRODOM with plasterboard as thermal insulation at the bottom side

The analysis show that from all three types of floor structures the RC slabs have the best performance at ambient temperature, as well as in case of fire. The performance of the slab system FERT when exposed to fire is satisfactory too, but we should not neglect its lower stiffness and greater deflections at ambient temperatures. The fire resistance of the contemporary floor structures (STYRODOM, ITONG, etc.) depends on the thermal insulation of the slab. The infill of extruded polystyrene-XPS is sensitive on temperatures over 240ºC, therefore we should no avoid these structures, but it is necessary to provide protective measures.

4. FIRE RESISTANCE OF ENERGY EFFICIEN EXTERIOR RC WALL

Fire spread through the facades is widely recognized as one of the fastest pathways of fire spreading in the buildings. The fire spread on a facade is influenced by both the location of the initial fire and its intensity. Actual fires as well as several fire tests have shown that a fire inside a building with a flashover has the most detrimental effect on the facade. The Flames reach lengths up to 5 m. The length of the flames depends on the fire load, the size and the geometry of the windows. They generally reach heights of two floors above the fire source, given a conventional height of the floors. The general safety goals are to ensure the load bearing capacity of the building over a defined duration, to avoid spread of fire to other buildings or fire compartments, to ensure the escape or the rescue of inhabitants and the safety of the rescue team.

Many combustible materials are used today in commercial wall assemblies to improve energy performance, reduce water and air infiltration, and allow for aesthetic design flexibility. One of these materials is the extruded polystyrene. The polystyrene is thermoplastic material which is temperature unstable. At 85-90°C shrinkage is activated, at 240-250°C melting process starts and at 280-290°C toxic gases are released. Because of these characteristics, whenever the polystyrene is used as insulation in the building façade, special measures have to be undertaken for improvement of the fire safety of the whole building.

Numerical simulation of external fire on a facade was done. The fire resistance of RC wall, with and without thermal insulation, was defined and the negative effect of the extruded polystyrene, as external insulation, in comparison with the rock wool insulation is recognized. The wall thickness was d=16cm. The siliceous aggregate concrete strength was f_c=30Mpa. The reinforcement ϕ12/12.5cm (RA400/500) was used on both sides and the concrete cover thickness was 3cm (for the longitudinal reinforcement). The load coefficient was 0.3 (the axial force at ambient temperature caused compression stresses 9.0 Mpa). Material properties of composite materials at room temperatures are given in Table 1 and Table 2. Three different cases were analyzed:

1. RC wall without any insulation, ISO 834 standard fire from inside and external fire curve [1] from outside;
2. RC wall with 2 cm mortar from inside and 5cm extruded polystyrene from outside, ISO 834 standard fire from inside and external fire curve from outside;
3. RC wall with 2 cm mortar from inside and 5cm mineral wool from outside, ISO 834 standard fire from inside and external fire curve from outside.

In case of RC wall without insulation the lowest fire resistance is achieved. At moment t=2.68 hours the RC wall failed in compression. The second case, with 2 cm mortar from inside and 5cm extruded polystyrene from outside, has much higher fire resistance t=5.0 hours, but after 18 minutes of external fire exposure the melting process started and this process is always followed by relies of toxic gases (Figure 11). After half an hour 2 cm of the thermal insulation is melted and after 1 hour almost the whole extruded polystyrene is melted and the temperature penetrates deep into the cross section (Figure 12).

Figure 11. Toxic gases released from the burning façade made of EPS

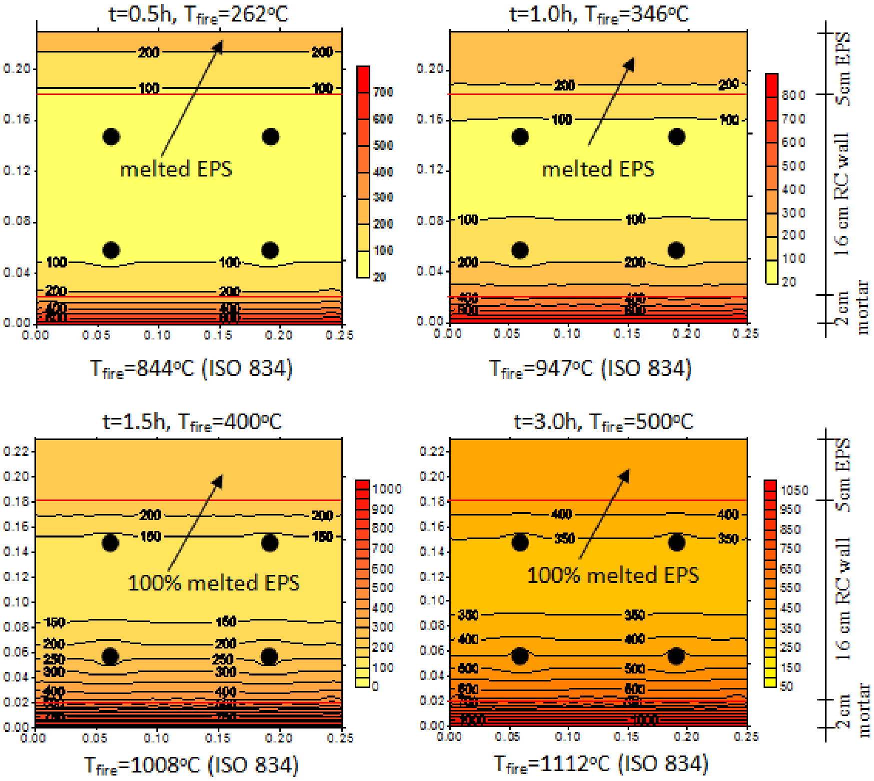

Figure 12 - Time redistribution of temperatures in the cross section of RC wall with thermal insulation of extruded polysyrene, exposed to fire from both sides

If mineral wool is used insteade of EPS (case 3), the thermal insulation stays stable even on temperatures higher than 600°C and there are no toxic gases. The temperatures in the cross section of the RC wall are lowest (Figure 13), concequently the fire resistance is highest and is t=6.55 hours.

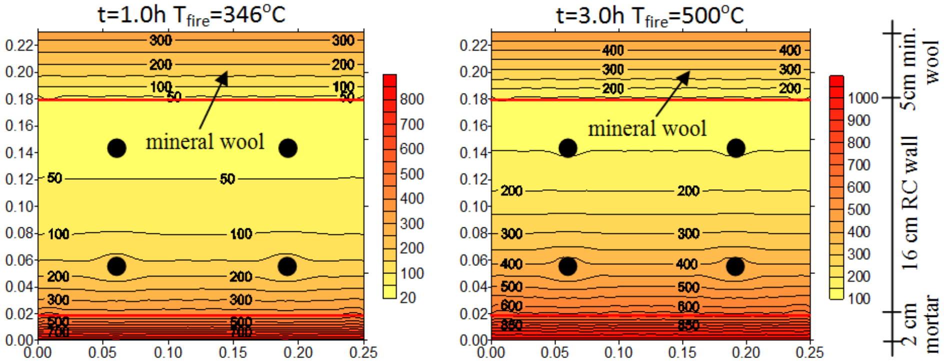

Figure 13. Time redistribution of temperatures in the cross section of RC wall with thermal insulation of mineral wool, exposed to fire from both sides

The testing method according the British standard BS 8414 is used for ETICS systems to prove their fire resistance and this test has revealed that façade fires can in fact spread very rapidly depending on the type of materials used. The advantage of the facade made of extruded or expanded polystyrene (ETICS facade) is that significantly reduces thermal transmission through outer walls and therefore helps to reduce the heating and cooling costs by 50% or more. This facade also greatly improves the living comfort – both in hot and cold climates. But the negative side is that the extensive use of combustible insulation materials in ETICS without proper fire protections and barriers were believed to contribute to the uncontrollable fire spread in the high-rise buildings.

5. CONCLUSIONS

The study clearly demonstrates that while energy-efficient construction techniques contribute significantly to sustainability goals, they introduce critical challenges to fire safety that must not be overlooked. Through detailed numerical analysis, it has been shown that the performance of floor structures and facade walls under fire conditions is highly dependent on the materials used, the configuration of insulation, and the fire exposure scenario. Timber-concrete composite floors with gypsum plasterboard and rock wool infill exhibited superior fire resistance, particularly when fire was applied from below. Similarly, reinforced concrete walls with mineral wool insulation significantly outperformed those using extruded polystyrene, which poses risks due to its combustibility and emission of toxic gases. These findings highlight the necessity of integrating fire safety considerations early in the design of energy-efficient buildings to ensure both sustainability and occupant safety are achieved.

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HAZARD MAPPING AND RISK ASSESSMENT – BUILDING FIRES

Suzana DRAGANIĆ[1], Mirjana LABAN[2]

[1]Assist. Prof. Dr, Faculty of Tecnical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, Serbia, suzanav@uns.ac.rs

[2] Full Prof. Dr, Faculty of Tecnical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, Serbia, mlaban@uns.ac.rs

Abstract

The increasing number of building fires with catastrophic consequences worldwide - particularly in high-rise residential buildings where fire spreads through combustible façade systems - emphasizes the urgent need to improve fire safety in such buildings. This paper addresses the importance of hazard mapping and fire risk assessment in urban environments, highlighting the role of spatio-temporal analysis in identifying and evaluating fire hazards. By integrating spatial data and building attributes, this approach enables comprehensive risk mapping, supports informed decision-making, and facilitates efficient planning of fire protection measures and emergency response strategies. The complexity of building façades and their material composition significantly influence fire behavior, as demonstrated through selected case studies. These examples underscore the need for innovative fire safety approaches, stricter regulations and improved implementation practices, particularly in densely populated areas. GIS-based tools and spatio-temporal analyses prove essential in urban fire risk management by revealing vulnerabilities and temporal risk patterns, ultimately contributing to effective mitigation strategies and enhanced resilience at both the building and urban scale.

Keywords: *Fire risk assessment, Hazard mapping, Building fires, Spatio-temporal analysis, GIS, Urban fire safety*

1. INTRODUCTION

Fire risk in the built environment is a complex issue resulting from the interaction between hazard and vulnerability (Figure 1). *Hazard* is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation (K-FORCE, 2019). *Vulnerability* is a complex characteristic that reflects weak points of system, its lowered resistance to potential disruption of its function, damage or destruction. It expresses a measure of damage done to system in case of dangerous events (K-FORCE, 2019).

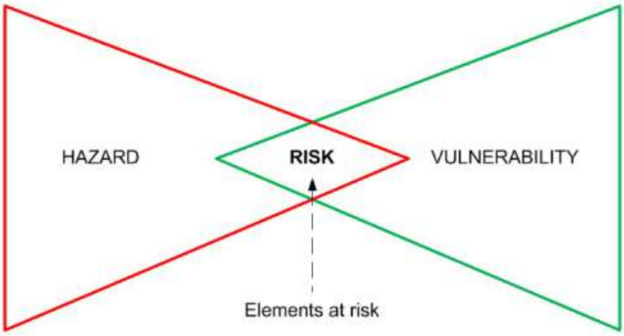

Figure 1 – Relationship between Hazard, Risk, and Vulnerability (Alexander, 2002)

In urban areas, building fires - particularly those involving combustible façade systems - pose a significant threat to human life, infrastructure, and the environment. The increasing frequency of these incidents worldwide, especially in high-rise residential buildings, highlights the limitations of current fire safety strategies and the urgent need for their improvement.

To assess fire risk effectively, numerous methods and tools have been developed. These methods are commonly classified into qualitative, quantitative, and semi-quantitative (combined) approaches. *Qualitative methods* evaluate risk descriptively, based on subjective engineering judgment, and are typically used for rapid assessment of potential fire hazards in a building and for considering various fire protection measures that need to be implemented to reduce risk. *Quantitative methods* provide a numerical risk value, where risk is calculated as the product of the probability of fire occurrence and the consequences of the fire, both expressed numerically. *Semi-quantitative methods* combine qualitative and quantitative approaches and can estimate risk in a simple, partially quantitative way when data access is limited. Both quantitative and semi-quantitative methods require detailed analyses and the availability of appropriate statistical data on fires. Past fires provide insight into how fires have spread and indicate the (in)effectiveness of measures implemented to meet the minimum technical requirements prescribed by regulations. However, the actual impact of each fire safety provision or combination of provisions is not measurable. There is insufficient statistical data on real fires involving external façade systems concerning fire frequency, fatalities, or extent of damage (Lamont & Ingolfsson, 2018).

In this context, hazard mapping in fire risk assessment has emerged as essential tool for identifying at-risk zones and guiding fire safety measures. When combined with spatio-temporal analysis, these methods provide a more precise understanding of fire behavior, enabling optimized mitigation strategies and emergency response planning at both the building and urban scales. Such approaches are fundamental for effective fire risk management and for reducing vulnerability, ultimately enhancing the resilience of urban environments to fire-related hazards.

This paper starts with an overview of significant high-rise building fires involving façades to illustrate practical risks and consequences (Section 2). Next, it reviews hazard mapping and fire risk assessment approaches, emphasizing the integration of spatial and temporal analyses to enhance fire risk understanding and management (Section 3). Finally, the conclusions highlight key findings and recommendations for advancing fire safety in urban environments.

2. BUILDING FIRES SPREAD VIA FAÇADES - AN OVERVIEW

Fires that have occurred worldwide over the past 20 years or more and that involved building façades (Figure 2) most commonly took place in residential buildings, and to a lesser extent in hotels and office buildings. The fires spread rapidly through the façade system and, in some cases, continued to spread into the interior of the building, affecting multiple floors. The materials that burned within the façade systems were predominantly low-density polyethylene used as the core of decorative aluminum composite panels or foam-based insulation materials. In some cases, foam insulation was installed beneath the decorative aluminum panel (Lamont & Ingolfsson, 2018).

Figure 2 – Map of building fires involving façade systems (Lamont & Ingolfsson, 2018)

In the context of injured and deceased individuals, as well as material damage, the consequences of fires in high-rise buildings can be significant. Therefore, high-rise residential buildings are considered high-risk in the event of a fire. A brief overview of selected high-rise building fires that spread via the façade is presented below.

A fire broke out in the high-rise residential building Grenfell Tower in London - home to around 500 people living in over 120 apartments - in June 2017 (Figure 3). The fire started in a fourth-floor kitchen due to a refrigerator malfunction and rapidly spread, eventually engulfing all 24 floors of the building. More than 70 people lost their lives and over 70 were injured in the incident (BBC News, 2017a; Rawlison, 2017). The building was originally constructed in 1974 and renovated in 2016. During the renovation, aluminum composite panels with a polyethylene core were installed as part of a ventilated façade system, placed over existing plastic-based insulation boards. The use of combustible materials in the façade system was the main reason the fire spread so quickly throughout the entire building. Subsequent investigations revealed that materials similar to those used in the renovation of Grenfell Tower had been installed in over 400 other high-rise residential buildings across the country. The high number of casualties prompted a comprehensive review and reassessment of fire safety regulations in the UK, across Europe, and beyond (BBC News, 2017b; Martin et al., 2017; Grenfell Tower Inquiry, 2019).

Figure 3 – Fire at the Grenfell Tower residential building in London, 2017 (BBC News, 2017a)

A fire broke out in a sixteen-story residential building in Baku (Azerbaijan), home to approximately 408 people living in 107 apartments, in May 2015 (Figure 4). The fire spread extremely rapidly and engulfed the entire building within a short period. The rapid spread was largely due to the presence of combustible façade cladding - polyurethane panels - which had been installed nearly 30 cm away from the existing concrete walls, creating a chimney effect beneath the cladding. These polyurethane panels were used in the renovation of more than 200 Soviet-era residential blocks in Baku. In this fire, 15 people lost their lives and over 60 were injured (Sindelar, 2015).

Figure 4 - Fire in a high-rise residential building in Baku, 2015 (Sindelar, 2015)

Over the past decade, more than 10 fires have occurred in buildings in the United Arab Emirates that spread via façades, which in most cases consisted of composite panels made of aluminum sheets with a polyethylene core. These incidents did not result in fatalities, as the building configurations and constructions allowed fire and rescue units to effectively combat the fires, and occupants to evacuate through zones protected from smoke and fire intrusion (BBC News, 2017c).

The Torch Tower in Dubai experienced two fires during its existence, in 2015 and 2017 (Figure 5). In both cases, the fire spread rapidly through the exterior cladding, which consisted of aluminum composite panels with combustible cores, similar to other fires in the city. A smaller fire was recorded in 2019 on the fifth floor of the building, with its spread promptly contained. No injuries were reported in these fires. The building was constructed in 2011 and comprises 79 floors and 676 residential units (Webster & Langton, 2017).

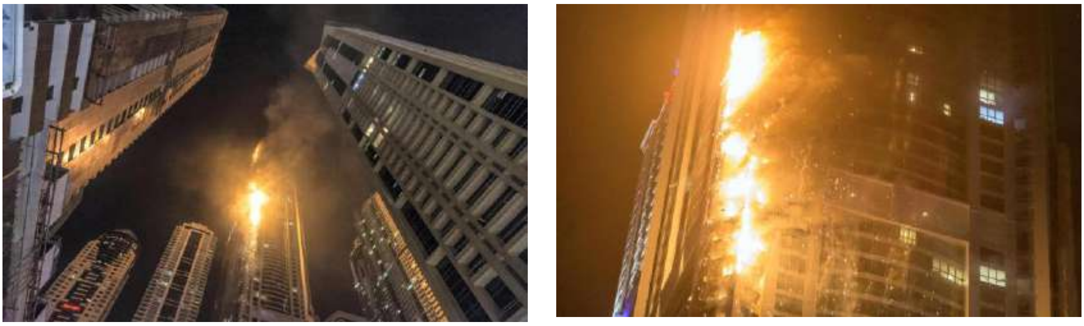

Figure 5 - Torch Tower in Dubai fire, 2017 (Webster & Langton, 2017)

As a result of a discarded cigarette butt, a fire broke out in 2012 in the city of Sharjah on the first-floor balcony of the Al Tayer residential tower (Figure 6), which has 408 residential units, 34 floors designated for living, and 6 floors for parking. No injuries were reported in the fire; however, 102 residential units were damaged, and burning droplets falling from the burning building damaged 45 cars parked nearby (Emirates 24/7, 2012; White & Delichatsios, 2014).

Figure 6 - The Al Tayer Building in Sharjah, Dubai, during and after the 2012 fire (Emirates 24/7, 2012; 2012b; Baldwin & Leon, 2012)

In Dubai, a fire broke out in 2012 on the 4th floor of the thirteen-story Saif Belhasa residential building, quickly spreading to multiple floors. The building has 156 residential units; the fire destroyed 9 apartments, and at least 5 cars were damaged by burning droplets falling from the façade. Several people were injured (White & Delichatsios, 2014).

In the same year, a fire also occurred at the Tamweel Tower (Figure 7), a 34-story building with 160 residential units. The fire started at the very top of the building and spread across the combustible façade. Due to the high temperatures, façade elements detached from the building. The fire was reportedly caused by a cigarette butt. Firefighting efforts lasted over 6 hours, and 600 residents were evacuated; fortunately, there were no injuries. The building was renovated in 2016, and residents began returning to their homes in 2017, five years after the fire (USA Today, 2012; Shabandri & Agarib, 2012; Leon, 2016; Badam, 2017).

Figure 7 - Tamweel Tower in Dubai during and after the 2012 fire (USA Today, 2012; Shabandri & Agarib, 2012; Leon, 2016)

In the city of Roubaix, France, a fire broke out in 2012 on a balcony on the second floor of the Mermoz residential tower (Figure 8). The fire spread along the façade, which had been renovated in 2003 with partial cladding of metal composite panels made of aluminum sheets with a polyethylene core. Video footage of the fire shows that the flames reached the top - the 18th and final floor of the building - within just a few minutes. Burning droplets falling from the façade onto the ground and balconies of lower floors were also observed. One person lost their life, and six others sustained minor injuries (White & Delichatsios, 2014).

Figure 8 – The Mermoz Tower in Roubaix, France, during and after the 2012 fire (Youde, 2017)

3. HAZARD MAPPING AND RISK ASSESSMENT

To create a risk map, it is necessary first to develop hazard and vulnerability maps. This process consists of the following steps (Rak & Jurikova, 2012):

- Data collection – gathering and preparing data;
- Data processing in the form of individual maps (hazard and vulnerability);
- Creation of the risk map by linking (overlaying) the hazard map and the vulnerability map.

Hazard maps illustrate the nature and extent of actual and potential hazards. The initial phase in hazard mapping involves collecting, comparing, and interpreting data on the nature, frequency, and magnitude of past events. The next step is to attempt to predict the nature and extent of future occurrences, which requires examining the probable frequency or likelihood of harmful events through statistical estimation and/or modeling. Maps can provide a relatively good understanding of what has happened in the past and indicate where future problems might occur; however, the reliability of hazard maps depends on the quantity and accuracy of source data, as well as the validity of prediction and modeling processes (Marker, 2013).

Vulnerability maps show locations where people, structures, and/or the natural environment are exposed to possible risk due to potential hazards.

Risk maps are essentially vulnerability maps enhanced by an assessment of the consequences of events of a given magnitude in terms of life loss, injuries, financial, environmental, and/or other impacts (Marker, 2013).

Over the past decade, technologies based on the collection and analysis of spatial and descriptive disaster data have been extensively applied to manage catastrophic events and fires. Since catastrophic events are fundamentally spatial in nature, the science of geospatial information plays a crucial role in managing these phenomena (Masoumi, van Genderen & Maleki, 2019).

Since the 1990s, *Geographic Information System* (GIS) has been a powerful tool for representing and analyzing layers of information spatially (Cariolet et al, 2019). GIS-based risk assessment methods can be adapted to assess fire risk in urban environments (Masoumi et al., 2019). In the analysis and evaluation of fire risk in buildings, GIS can be used for mapping fire hazards, vulnerabilities, and risks and presenting them in a spatial format. Besides the spatial aspect, the temporal domain also plays a very important role in risk analysis, as fire distribution in buildings varies depending on the time of day, week day, month, and even the season. Understanding fire behavior in buildings across space and time provides an opportunity to direct fire protection improvement measures toward buildings identified as having high fire risk through such analysis.

This section presents a brief overview of studies dealing with fire risk assessment in urban environments based on hazard mapping and spatial and/or temporal fire analysis. Asgary et al. (2010) conducted a spatio-temporal GIS analysis of fire incidents that occurred in Toronto, Canada, from 2000 to 2006 (Figure 9). The study involved collecting and analyzing data on various fire causes with the aim of determining to what extent existing data can be used as a basis for improving fire prevention and response at local levels. The research applied spatio-temporal techniques to illustrate how the patterns of the analyzed fires vary depending on the time of day, day of the week, and month of the year.

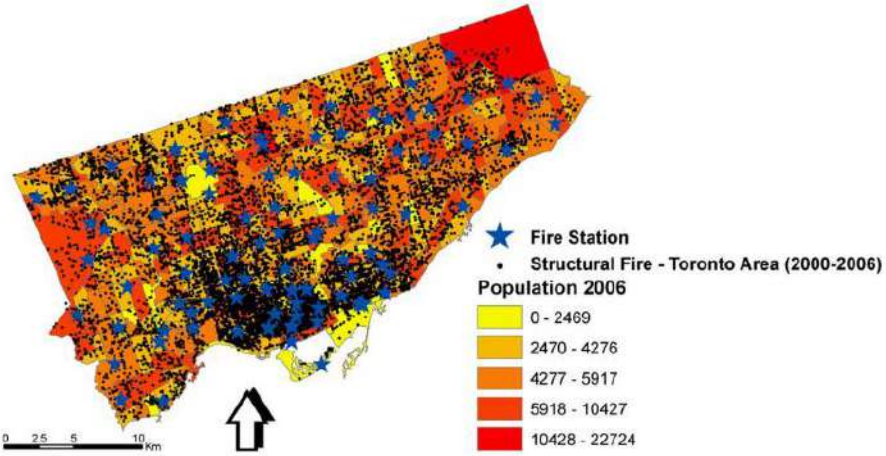

Figure 9 - Building fires in Toronto from 2000 to 2006 and Fire and Rescue Unit locations (Asgary et al., 2010)

Srivanit (2011) developed a GIS-based fire risk assessment approach aimed at identifying spatial factors influencing fire hazard and assessing risk in the city of Chiang Mai, Thailand. The fire risk assessment in this study focused on two main factors: vulnerability and the capacity to mitigate disaster impacts within the studied area, as well as within areas where previous fires had been recorded. The collected information was integrated into a GIS database, followed by a spatio-temporal analysis (Figure 10).

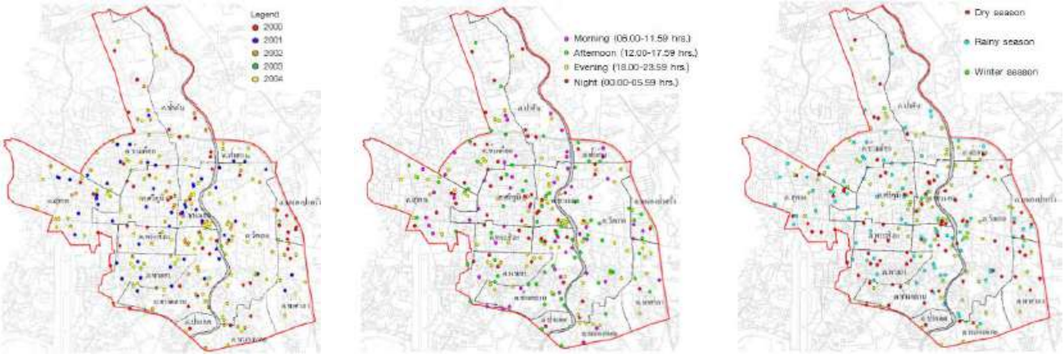

Figure 10 - Patterns of fire incidents in Chiang Mai city during 2000–2004 by time period: a) by year; b) by time of the day; c) by season (Srivanit, 2011)

Špatenková and Virrantaus (2013) conducted a study focusing on the probability of incident occurrence and presented a set of advanced interdisciplinary spatial and spatio-temporal analysis methods sharing the common goal of identifying causal relationships within incident data. The study aimed to uncover relationships between building fire occurrences and the surrounding environment, including the socio-economic characteristics of residents. It demonstrated how each method reveals different aspects of existing relationships and how diverse insights can be drawn from spatial data sets. The approach was illustrated through a case study analyzing building fires in the city of Helsinki, Finland, that occurred between 2005 and 2007 (Figure 11).

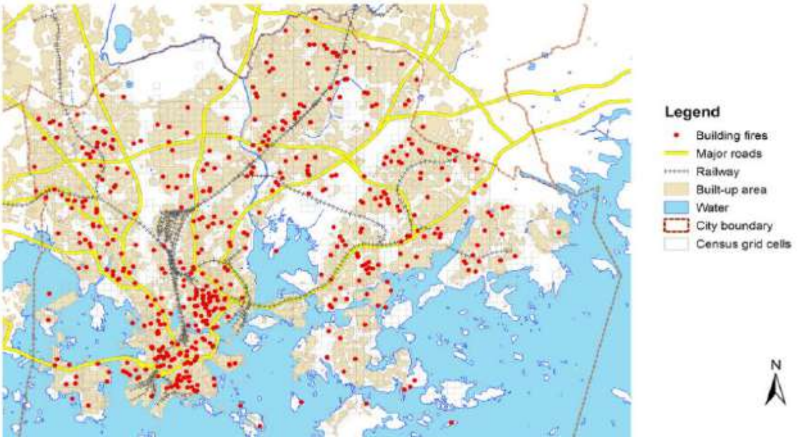

Figure 11 - Distribution of building fires in Helsinki, Finland, 2005–2007 (Špatenková & Virrantaus, 2013)

Ferreira et al. (2016) developed a new methodology for assessing fire risk in urban environments, which they applied to the historic city center of Seixal, Portugal (Figure 12). Using the developed methodology, more than 500 buildings were assessed, and the results were spatially analyzed using an integrated GIS system. The first phase of the case study involved identifying and collecting the main sources of fire vulnerability. In the next phase, this data was used as input for the development and application of the new fire risk assessment methodology.

Figure 12 - Fire risk map of the urban core of Seixal, Portugal (Ferreira et al., 2016)

Gonçalves and Correia (2016) proposed a method for assessing fire risk in urban environments. The aim of the study was to create a detailed fire risk map and intervention plans that would enable better response and mitigation of the effects of urban fires. The study employed the *CHICHORRO* method, a new approach to fire risk assessment in cities, which was applied in a case study conducted in Porto, Portugal. The outcome of the research was a fire risk map for the study area (Figure 13).

Figure 13 - Fire risk map of the Ribeira/Barredo block in the historic center of Porto, Portugal (Gonçalves & Correia, 2016)

Masoumi et al. (2019) assessed the fire risk of high-rise buildings in a densely populated urban area of Zanjan, Iran, considering two main aspects: characteristics of the urban infrastructure and features of the buildings themselves. To develop fire risk maps, various types of information were collected and information fusion techniques were applied using spatial analysis. For this purpose, spatial data for each building were collected using drones, followed by the collection of attribute data. Taking into account the characteristics of the urban infrastructure associated with high risk, as well as fire protection analysis of high-rise buildings, a vulnerability map for the area was created. The fire hazard level of each building was assessed, and the overall risk level was determined (Figure 14).

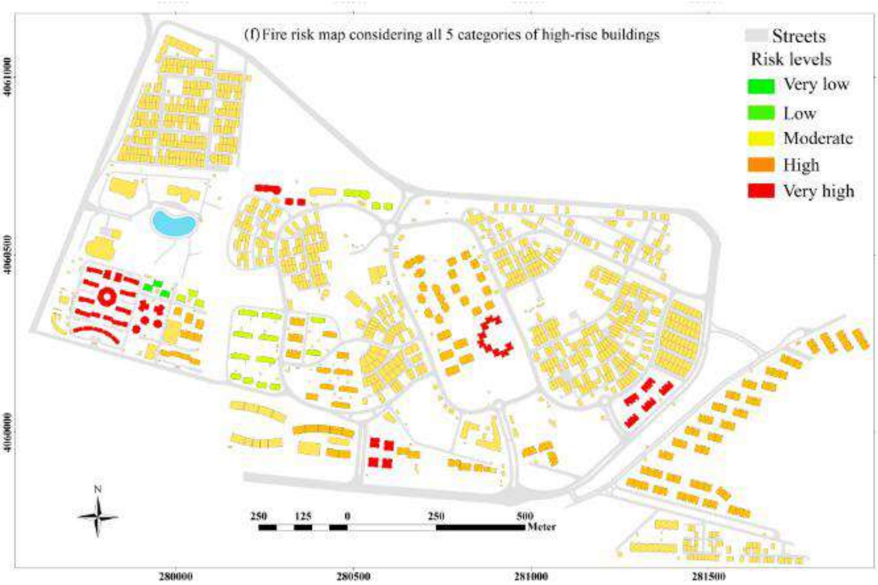

Figure 14 – Fire risk map of the case study area based on building characteristics and urban infrastructure (Masoumi et al., 2019)

4. CONCLUSION

Building façades are complex systems whose design and material composition significantly influence fire behavior in the event of a fire. The case studies analyzed highlight the risks associated with the use of combustible materials in façades and also demonstrate the need for innovative fire safety approaches, stricter regulations and improved implementation practices, especially in densely populated urban environments.

The reviewed hazard mapping and risk assessment methodologies confirm the essential role of spatio-temporal fire risk analysis in urban fire management. GIS-based tools facilitate a spatially informed approach to identifying vulnerabilities and planning interventions, while temporal patterns provide insights into when buildings are most at risk.

Key conclusions from the analysis include:

- The number of casualties by urban fires highlights the urgent need for proper assessment of building fire risk, especially in older urban areas. This is essential for risk mapping and for developing emergency intervention plans that enable better response and more effective mitigation of the impacts of urban fires.

- Risk mapping, that is, the integration of risk analysis results into a GIS platform, plays a crucial role in fire risk management. It represents a key step toward risk mitigation at the urban level by enabling intervention planning based on a comprehensive spatial overview of the analyzed location, which helps minimize fire hazards and contributes to the development of more accurate and comprehensive risk mitigation strategies.
- Spatio-temporal fire analysis allows for the creation of more accurate risk maps. In addition to spatial analysis, risk modeling should also include detailed temporal analysis.
- To ensure the reliability of analysis results, high-quality input data must be provided. The data collection and storage process should be fully automated to ensure the highest level of record quality.

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ENERGY EFFICIENCY AND FIRE SAFETY IN BUILDINGS UNDER RENOVATION WAVE

Suzana DRAGANIĆ[1], Mirjana LABAN[2]

[1]Assist. Prof. Dr, Faculty of Tecnical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, Serbia, suzanav@uns.ac.rs

[2] Full Prof. Dr, Faculty of Tecnical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, Serbia, mlaban@uns.ac.rs

Abstract

The renovation of European Union's building stock by improving the energy performance of existing buildings is a crucial factor in achieving ambitious energy and climate goals and fostering a sustainable built environment, as buildings are significant contributors to energy consumption, GHG emissions and resource use. Improving a buildings' energy performance through renovation can make a building more sustainable but can also increase the fire load of the building and change the way the building responds to a fire. Energy renovation is a good starting point to tackle both the energy efficiency requirements and the fire safety challenges. By taking a holistic approach that considers both energy efficiency and fire safety, we can create buildings that are truly sustainable, safe and resilient, positively impacting society and the environment. Presented case study uses a strategic model, developed for the building renovation process, consisted of eight stages, which require a multidisciplinary approach through the combined application of methods, technologies and digital tools often applied in contemporary science and engineering practice. The model enabled a contemporary approach to the assessment of high-rise residential buildings' facades, from the aspects of energy efficiency and fire safety.

Keywords: High-rise residential buildings, Facades, Energy efficiency, Fire safety, Assessment, Renovation wave

1. INTRODUCTION

Europe has pledged to become the first climate-neutral and sustainable continent by 2050. To reach this ambitious goal, the European Union (EU) has set intermediate targets for 2030 in terms of reducing greenhouse gas (GHG) emissions (by at least 55%), increasing the share of renewable energy (by at least 32%) and improving energy efficiency (by at least 32.5%), compared to 1990 levels (European Union, 2023).

Although occupy just 3% of the earth's land, cities have a key role to play in this effort, as they account for two-thirds of global energy demand and 70% of carbon emissions (Fausing, 2020). As the largest energy consumer in the EU and one of the largest CO_2 emitters, the built environment has a significant impact on many sectors of the economy and quality of life (European Commission, 2020a).

The present urban lifestyle is one of the fundamental causes of many environmental problems that humanity faces today (The Aalborg Charter, 1994). As almost 70% of the world's population is expected to live in cities by 2050, our future is undeniably urban and sustainable development cannot be achieved without significantly transforming the way urban spaces are built and managed. "Sustainable cities and communities" is one of 17 Sustainable Development Goals (SDGs) established by the United Nations General Assembly in 2015, with the official mission to "*make cities inclusive, safe, resilient and sustainable*" (United Nations, 2023).

The renovation of European Union's building stock by improving the energy performance of existing buildings is a crucial factor in achieving ambitious energy and climate goals and fostering a sustainable built environment, as buildings are significant contributors to energy consumption, GHG emissions and resource use. Improving the energy efficiency of building stock would cut emissions, tackle energy poverty, reduce people's vulnerability to energy prices and support the economic recovery and job creation (European Commission, 2021).

In order to be sustainable, energy-efficient buildings should also be resilent, healthy, affordable, safe, comfortable to use and durable. The COVID-19 pandemic also has brought to the forefront the significance of living in healthy and safe buildings. As people spent more time indoors, the quality of their living environment became increasingly important.

Improving a buildings' energy performance through renovation can make a building more sustainable but can also increase the fire load of the building and change the way the building responds to a fire, unless non-combustible materials are used (Kelly Spillane, 2021). When enhancing energy-efficiency, building's fire safety should not be impaired.

The increase in building fire events over the last decade indicates that existing fire safety regulations are lagging behind new technologies, materials and innovative construction and design, increase the inherent fire risk and compromising the safety of building users. Consequently, energy renovation is a good starting point to tackle both the energy efficiency requirements and the fire safety challenges. By taking a holistic approach that considers both energy efficiency and fire safety, we can create buildings that are truly sustainable, safe and resilient, positively impacting society and the environment.

Previous research (Laban, 2012) has indicated the unsatisfactory technical condition of façade elements and very low fire safety level of the buildings constructed in Novi Sad, Serbia between 1961 and 1990. Data from the firefighting service in Novi Sad indicate a steady increase in the number of fires in multi-story residential buildings, as well as a growing percentage of such fires in the total number of all fires. After many years of exploitation and a lack of regular maintenance, there is a need to renovate and improve façade performance, in order to comply with the requirements of current technical regulations and standards.

The paper presents the verification and validation of a assessment phase of strategic model, developed for planning and designing the renovation of concrete facades of free-standing high-rise residential buildings from the aspect of energy efficiency, durability and fire safety. The strategic model is the result of theoretical and research work presented within a doctoral dissertation (Draganić, 2022), with a specific focus on high-rise residential buildings constructed in Novi Sad between 1961 and 1990. The verification and validation of the renovation model was carried out on a freestanding high-rise (13-storey) residential building, built in 1972 in Novi Sad, Serbia. The model enabled a contemporary approach to the assessment of high-rise residential buildings' facades, from the aspects of energy efficiency and fire safety.

2. BACKGROUND

2.1. Energy efficiency and fire safety in buildings

The building sector plays a central role in the EU's energy-saving policies and is recognized as a key sector for achieving the energy and climate goals for 2030 and transition to clean energy (European Commission, 2019a). It is also crucial for meeting the long-term objectives aimed at achieving a highly energy-efficient and decarbonized building sector by 2050 (Directive 2018/844).

The increase in population, with 90% of their time spent indoors, heightened demands for building functionality and the quality of indoor environments, along with global climate change, have led to a dramatic rise in energy consumption in buildings over the past decade. Building sector accounts for 40% of energy consumed in Europe and for 36% of CO_2 emissions (European Commission, 2019b), which makes it the largest consumer of energy, but also a sector with significant potential for reducing energy demand.

A large share of today's EU building stock was built without any energy performance requirement. One third (35%) of the EU building stock is over 50 years old, more than 40% of the building stock was built before 1960 and 90% before 1990. Almost 75% of it is energy inefficient according to current building standards and 85-95% of the buildings that exist today will still be standing in 2050 (Figure 1) (European Commission, 2020b; Filippidou & Jimenez Navarro, 2019).

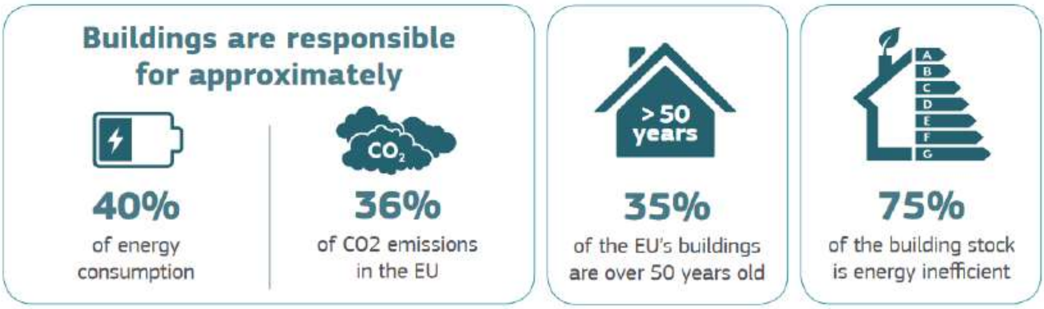


Figure 1 – The building sector in Europe: facts and figures (European Commission, 2019c)

The Directive on Energy Performance of Buildings (EPBD) (Directive 2018/844) is the cornerstone of European legislation for transforming the building sector. In order to achieve the set climate and energy goals, Member States (MS) are required to adopt long-term renovation strategies and increase the renovation rate, as well as to establish minimum requirements for energy performance for both new buildings and existing buildings that are subject to major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls. Directive also obligates all MS to ensure that from 2021 onwards, all new buildings are "nearly zero-energy buildings".

The European Green Deal strategy (European Commission, 2019d) identified building renovations as a key tool to reduce emissions and provide a healthy and affordable living and working environment for all. Increasing renovation rates to almost 3 % and renovating 210 million existing buildings could create up to 2 million jobs in the construction sector, which accounts for about 9 % of the EU's GDP and is an important part of the recovery strategy after the COVID-19 crisis, and could contribute to a clean economy (European Parliament, 2020).

At the same time, energy efficiency renovation presents a valuable opportunity to upgrade the fire safety of buildings, and this aspect should not be overlooked. In Europe, over 5,000 fires incidents occur daily. Annually, 70,000 people require hospitalization due to severe fire-related injuries, and 4,000 people die in fires, while 90% of all fire victims are killed by fires in buildings. Emissions of smoke, toxic gases, and other particles negatively impact our environment and health. In 2012, fire-related air pollution in the EU resulted in 403,000 deaths. Fires also affect communities, businesses, families, and workers, leading to high costs for medical treatment and counseling, long-term care needs, displacement from homes or jobs, and more. In the most advanced countries, the total economic losses associated with fires amount to 1% of European GDP (Figure 2) (Andolfatto, 2020; Dyrbøl, 2020; Fire Safe Europe, 2023).

EU acknowledges the importance of addressing the fire safety during renovation. Fire safety aspects should be considered during the design, selection of materials, construction, renovation and operation of buildings in order to improve prevention, detection, early suppression, evacuation, compartmentation, structural resistance and fire-fighting, as well as the relevant competencies of involved professionals (European Parliament, 2020), and

MS should be able to use their long-term renovation strategies to address fire safety issues which affect energy efficiency renovations and the lifetime of buildings (Directive 2018/844). By integrating fire safety measures into renovation projects, buildings can become more resilient to fire incidents.

Figure 2 – Fire safety in Europe: facts and figures (Draganić et al, 2023)

2.2. Renovation wave

In 2020, the European Commission (EC) released *A Renovation Wave for Europe* - a strategic document accompanied by an action plan, aimed to accelerate the renovation of existing buildings across the EU and make them more energy-efficient, sustainable, and resilient. It is stated that, despite the potential benefits, only 0.4-1.2% of the building stock is renovated each year. At the current pace, the decarbonisation of the building sector would require centuries (Buildings Performance Institute Europe [BPIE], 2021).

The Renovation Wave aims at adopting a holistic perspective on EU buildings policy, going beyond solely the EPBD measures. Initiative strives to address the challenges of climate change, reduce greenhouse gas emissions, and enhance the sustainability of the built environment. It provides concrete actions and guidelines for increasing building renovations and encourages MS to develop renovation strategies and take measures to improve the energy efficiency of buildings.

The objective is to at least double the annual energy renovation rate of both residential and non-residential buildings by 2030 and to foster deep energy renovations. Mobilizing forces at all levels towards these goals will result in 35 million building units renovated by 2030.

The initiative prioritize action in three areas:

- tackling energy poverty and worst-performing buildings,
- renovating public buildings, such as administrative, educational and healthcare facilities and
- decarbonizing heating and cooling.

These areas should be considered as a priority for policy and financing, because they offer huge potential for increasing renovation rates, while delivering large energy savings and healthier and more comfortable buildings for citizens.

To address untapped energy efficiency potential in the building sector and increase the building renovation rate, the EC proposes introducing mandatory *Minimum Energy Performance Standards* (MEPS) (Kamenders et al, 2022) in the building sector as part of its Renovation Wave strategy.

The recast EPBD (EPBD 2024/1275), which entered into force in 2024, introduces EU–level MEPS for the worst-performing buildings and leaves MS the scope to set their own standards in addition. MEPS require selected existing buildings to meet a required minimum level of energy performance by a future date or trigger point in the building lifecycle (sale or rent). The focus on the very lowest performing classes of the building stock ensures that efforts focus on buildings with the highest potential for decarbonisation, energy poverty alleviation and extended social and economic benefits. MS shall also, as part of the national building renovation plans, establish specific timelines for achieving higher energy performance classes, in line with their pathway for transforming the national building stock into zero-emission buildings. The proposal also introduces "renovation passport" - a document that provides a tailored roadmap for the deep renovation of a specific building in a maximum number of steps that will significantly improve its energy performance.

In the context of fire safety, recast EPBD states that MS shall ensure that new buildings adhere to fire safety standards as well as address the compliance of buildings undergoing major renovation to fire safety standards. The renovation passport shall comprise wider benefits related to fire safety, inter alia. MS shall put in place inspection schemes including digital tools to certify that the delivered construction and renovation works meet the designed energy performance and are compliant with fire safety requirements as laid down in by the building codes or equivalent regulations.

As a member of the *Energy Community*, the Republic of Serbia (RS) is obligated to implement EU directives related to energy efficiency and energy performance of buildings into the national legislation. In 2022, the Government of RS has adopted a *Long-term strategy for inciting investments in the renewal of the national buildings fund until 2050* (The Government of Republic of Serbia, 2022). The main goal of the strategy is to define building renovation measures, based on the established building stock characteristics, defined model buildings and performed cost-optimal analyzes. Five possible scenarios of renewal have been prepared. The first, the main scenario, entails unsubsidized renewal and construction according to the current regulations, while the last, most advanced one, entails the building renovation to the level of nearly zero-energy buildings. In the context of fire safety it is stated that renovation measures must ensure equivalent or superior fire safety for occupants than the existing buildings.

3. METHODOLOGY

The applied strategic model for the renovation of concrete facades of high-rise residential buildings is based on an assessment of the current condition and established renovation criteria, aiming to enhance the thermal performance of exterior walls, extend the durability of building facades, and ensure the required level of fire safety, while preserving the architectural identity of the buildings.

The strategic model is the result of theoretical and research work presented within a doctoral dissertation (Draganić, 2022), with a specific focus on high-rise residential buildings constructed in Novi Sad between 1961 and 1990 (Figure 3).

Figure 3 – High-rise residential buildings built in Novi Sad, Serbia, in period 1961-1990 (70 buildings)

According to the applied model, the building renovation process consists of eight phases whose realization requires a multidisciplinary approach involving the combined application of methods, technologies, and digital tools commonly used in contemporary science and engineering practice.

Within the proposed model, the assessment of buildings' facades represents the fifth phase of the renovation process and includes three assessments:

I. Durability assessment,

II. Energy performance assessment, and

III. Fire safety assessment.

Following the facades' assessment, a comparison is conducted between the existing condition and the required condition, as defined by legal regulations, technical codes, standards, and/or project specifications. Additionally, the required condition regarding fire safety is determined based on the established level of acceptable risk.

If the building meets the specified requirements, postponement of renovation is recommended, along with regular inspections to monitor the consistency of performance. If the required quality criteria are not met, measures and solutions are proposed to improve the current condition.

3.1. Energy performance assessment

The determination of the compiliance with energy efficiency requirements is carried out by preparing an *Energy Efficiency Elaborate*, in accordance with the applicable Rulebook on Building Energy Efficiency (2012), where the assessment covers the verification of the building's thermal protection on two levels:

1) At the level of individual building components, by examining heat transfer, water vapor diffusion, and summer stability;
2) At the level of the building as an energy unit, by determining thermal gains and losses, specific annual energy requirements for heating, and the building's energy class.

Additionally, the identification of thermal bridges in the thermal envelope is provided through photographs taken by a thermographic drone.

3.2. Fire safety assessment

For fire risk assessment, the model proposes the application of a multi-level methodology developed as part of a doctoral dissertation, unique in our region and in accordance with the latest trends in the field of risk analysis, which includes:

1) Space-temporal analysis of fire distribution in residential buildings using the Fire Hazard Map;
2) Mapping and analysis of the buildings' fire risk using the Fire Risk Map;
3) Quality control of the buildings' fire safety performance using the checklist method;
4) Assessment of risks regarding the requirements for the installation of a system for automatic detection and notification/fire extinguishing using the Euroalarm semi-quantitative method;
5) Quantitative assessment using the event tree method;

The quality control of the building's fire safety performance includes the determination of the initial risk level and is carried out on the basis of an analysis of the building characteristics and the fire safety measures implemented in the building.

The proposed qualitative assessment model is based on the control of the fulfillment of the minimum technical requirements systematized in a checklist, identified by the analysis of the current national technical regulations in Serbia. The conformity of evacuation routes of the analyzed high-rise residential building with the fire safety requirements is verified on the basis of the completed and analyzed checklist, created within the framework of previous research (Draganić, 2022), where these conditions are indicated with a qualitative description. YES/NO answers are given on the basis of the fulfillment of the mentioned fire safety requirements.

The result of the conducted analysis is a list of potential fire hazards, which enables defining the minimum corrective measures that need to be implemented in order to improve the current situation and thus reduce the risk of fire.

4. CASE STUDY

The analyzed high-rise residential building (Figure 4) is located in the Liman III area, 3.0 km from the professional fire-rescue unit. The building is freestanding, consists of cellar, ground floor and 13 floors, with a total height of approx. 42m. The building is built in IMS precast system, with rectangular base (15.2m x 22m). It has one main entrance with windshield and external access staircase and ramp. Vertical communication is provided by a centrally positioned single-flight staircase and two elevators. The roof is flat, impassable. There are 55 apartments in the building, three on the ground floor and four apartments on each upper floor.

(a) (b)

Figure 4 – Analyzed high-rise residential building NF-26: (a) location of the building on the map of Novi Sad and (b) building's southeast façade

4.1. Energy performance assessment

To evaluate the energy performance of the analyzed building and determine compliance with energy efficiency requirements, an *Energy Efficiency Elaborate* was prepared.

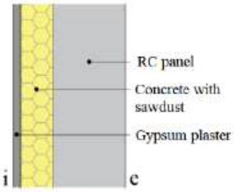
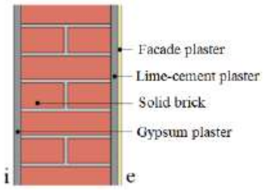
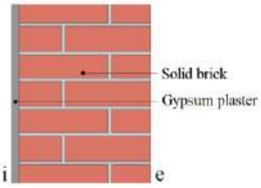
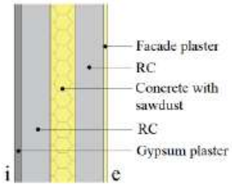
The building is characterized by a favorable shape factor, slightly higher than usual for high-rise buildings. Transparent surfaces make up 45% of the total façade area. The building is free-standing, with all façades exposed to prevailing winds due to its open location. Its longer axis is oriented north-south. Shadow analysis revealed that a neighboring structure partially obstructs sunlight on the southern and eastern façades, while the eastern façade in lower floors is shaded by deciduous trees during the summer. All four façades are moderately shaded by their own balconies and loggias.

Thermal comfort in the building is achieved through a district heating system in the winter and local air conditioning units in the summer. During summer, blinds provide protection for the transparent surfaces of the building. Thermal comfort is also partially ensured by thermal insulation incorporated into the walls of the building's thermal envelope.

Air comfort is provided by natural ventilation through façade openings (windows and doors). Considering the building's construction period, it is assumed that the building has poor airtightness. Light comfort is achieved through natural lighting - daylight entering the building through an adequate number of façade openings, as well as artificial lighting.

Acoustic comfort is partially ensured by walls of appropriate thickness and structure, as well as proper spatial organization. However, it is compromised due to the poor sealing of façade joinery. In the structure of the building's thermal envelope, 28 assembly components were identified, none of which meet the specified criterion regarding the maximum value of the thermal transmittance coefficient. Table 1 presents the identified assemblies of external walls.

Table 1- The assemblies of external walls in the thermal envelope the NF-26 building

External walls - Umax= 0,4 W/(m^{2}K)			
SZ-01	SZ-02	SZ-03	SZ-04
			
U = 1,49 W/(m^{2}K)	U = 1,77 W/(m^{2}K)	U = 1,43 W/(m^{2}K)	U = 1,26 W/(m^{2}K)

The analysis of thermographic images (Figure 5) clearly reveals thermal bridges in the areas of edge beams and columns on reinforced concrete walls, as well as in the edge zones of parapet walls and façade joinery.

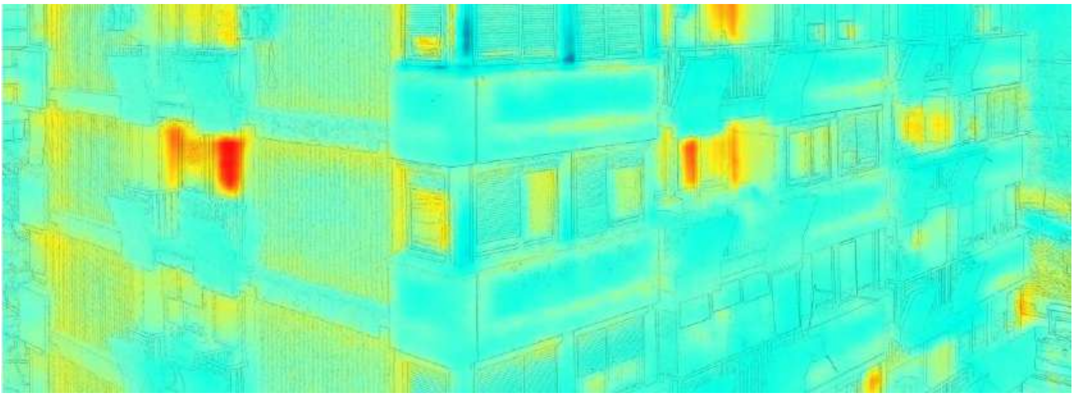


Figure 5 – A thermographic drone photograph of the façade: noticeable heat losses through the reinforced concrete walls, particularly in the areas of edge beams and columns, in the inter-floor structure zone, at parapets connecting the load-bearing and exterior concrete layers, and in the areas around the original windows

The largest contribution to total energy losses comes from transmission losses through windows and doors (36.5%), followed by transmission losses through the non-transparent part of the building envelope (31.4%).

Based on the calculated specific annual heating energy demand (162.17 kWh/m²a, Figure 6), the building is classified in energy class F.

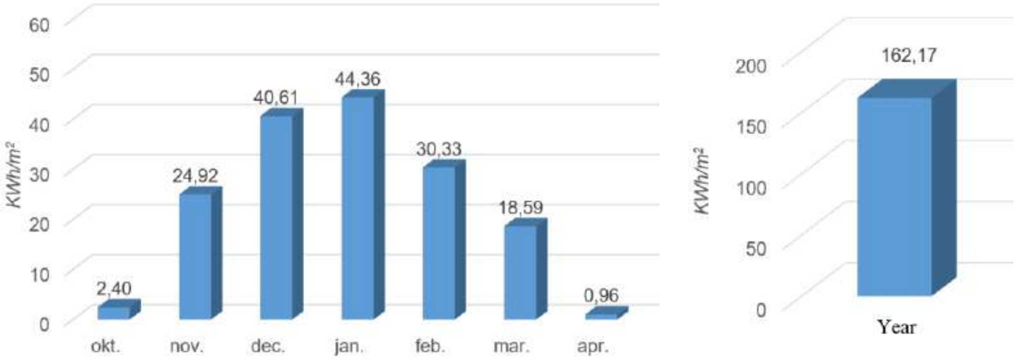


Figure 6 – Monthly and annual heating energy demand diagrams for the NF-26 building

The first level of energy renovation considered the replacement of facade joinery and the flat roof system, as well as thermal insulation of the floor structure above the unheated space. The second level, in addition to applying the first level measures, also considered the installation of an additional layer of thermal insulation on the exterior walls. Evaluation results of the proposed measures show that implementing first-level measures improves the building's energy rating from F to D, while applying second-level measures achieves an energy rating of C.

4.2. Fire safety assessment

In the context of evacuation routes' fire safety, the building meets less than half of the specified requirements.

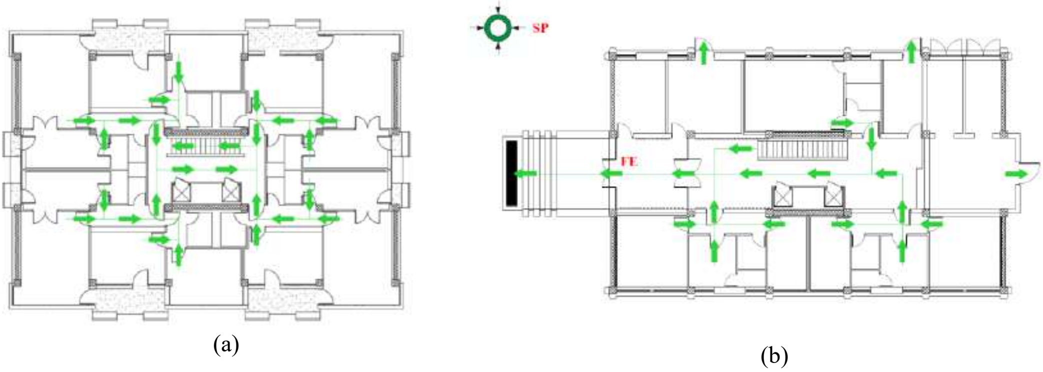
In addition to the lack of fire compartments, one of the major deficiencies of the building is that there is neither an evacuation corridor nor a safety staircase in the building.

In the event of a fire, tenants are evacuated from the starting point to the first exit - from the apartment, through the hallway to the staircase, by the staircase to the ground floor, then through the entrance hall and windshield area to the final exit (FE) and over the plateau and the access staircase to a safe place (SP) which is located at an adequate distance from the building (Figure 7).

Tenants who may find themselves in the basement in the event of a fire are particularly at risk, as the basement does not have a separate exit and is connected to the upper floors by a common staircase, resulting with evacuation via the main exit on the ground floor.

Revolving doors that open in the direction of evacuation are located at each exit on the evacuation route, except at the first exit (apartment doors) where this is not required. The width of the doors complies with the established criteria.

The staircase width is 1.10 m and the hall width, in its narrowest part, is 1.20 m, which do not meet the required conditions (1.25 m). Visual inspection of the building revealed obstacles (potted flowers and furniture) which narrow the evacuation route and consequently could hinder the evacuation only on the top floor (Figure 8).



(a) (b)

Figure 7 – Evacuation route from the building: (a) evacuation from the apartments on the characteristic floors; (b) evacuation from the ground floor premises, through the final exit (FE) to the safe place (SP);

(a) (b) (c)

Figure 8 – Evacuation routes: (a) insufficient width of the main staircase and hallways; (b) obstacles in the form of potted plants; (c) obstacles in the form of furniture;

The path to the last exit door leads through the entrance hall and the windshield area (Figure 9a), which is not locked. The dimensions of the windshield area meet the established criteria, while the height of the final exit is lower than prescribed. The exit and exit access are mostly accessible, while potted flowers in the entrance lobby and windshield area can be an obstacle during evacuation.

The last exit from the building leads to a safe area - directly to the street. The exit door is made of shatterproof glass and has a physical barrier at a height of 90 cm, although it is not marked at a height of 140 to 160 cm as required. In front of the exit there is a flat pedestrian plateau and an access staircase with appropriate dimensions. The ramp for pedestrians and wheelchair users is considered non-functional due to inadequate slope and width (Figure 9b).

The building does not meet any of the established criteria related to evacuation signs and emergency lighting. There is no emergency lighting on evacuation routes nor signs indicating the direction of evacuation. Some doors do not have markings indicating their proper purpose.

(a) (b)

Figure 9 – Building entrance: (a) potted plants in the entrance hall and vestibule that may pose an obstacle during evacuation; (b) an access staircase with appropriate dimensions and non-functional ramp for pedestrians and wheelchair users (inadequate slope and width);

The results of the qualitative assessment, conducted using the newly created checklist, indicate that the fire safety of the analyzed building is at a very low level in relation to evacuation routes, as there is no evacuation corridor and no safety staircase. The process of evacuation from the building in the event of a fire can be considered unsafe, as occupants would be moving through the area where the penetration of flames and smoke from the apartments and other premises affected by the fire is not prevented. Unlit and unmarked evacuation routes, as well as narrow evacuation route also contribute to difficult evacuation conditions and would lead to the crowding of people and the formation of bottlenecks, significantly compromising tenant safety in the event of a fire.

In order to improve the existing fire safety of evacuation routes in analyzed building, and the evacuation process in general, the following measures are proposed:

- Construction of two external safety staircase, accessible from each apartment,
- Reconstruction of the external ramp for pedestrians and wheelchair users,
- Installation of emergency lighting on the evacuation routes,
- Marking all exits, evacuation routes, doors, passages and staircase with visible and appropriate signs,
- Educating and informing tenants through evacuation drills, organized at least once every five years;

5. CONCLUSION

The renovation of existing buildings aligns with the overall EU's objectives of decarbonization, energy efficiency and sustainability, and can significantly contribute to combating climate change and creating a more resilient and sustainable built environment for present and future generations.

Sustainable building design should go beyond mere energy efficiency and environmental protection and encompass fire safety as integral components. With the introduction of new sustainable materials and technologies in the renovation process, it is essential to evaluate the fire risks associated with these new elements, especially concerning flammability and toxicity. Within the emergence of new tools such as the MEPS, it is crucial to factor in fire-safety. Sustainable buildings must be fire safe, thus energy-efficient renovations must integrate fire-safety.

The synthesis of the results from the comparative analysis of current and required performance of the buildings, derived from the conducted case study, highlights several key improvement needs:

- Energy efficiency, where replacing the facade joinery is necessary due to the high proportion of transparent surfaces in the thermal envelope, resulting in savings of up to 50% in energy consumption. Additional savings of up to 70% can be achieved by applying thermal insulation to exterior walls.
- Fire safety, where ensuring timely and efficient evacuation in case of fire is essential by installing automatic fire detection and alarm systems and safety staircases or an automatic fire extinguishing system.

The proposed model enables a methodological approach for improving the condition of existing buildings towards a sustainable built environment, while retaining the inherited values and advantages of the buildings.

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SPATIOTEMPORAL ANALYSIS OF FIRE HAZARD DISTRIBUTION

Mirjana LABAN[1], Suzana DRAGANIĆ[1], Marko MARKOVIĆ[1], Ljiljana POPOVIĆ[1], Srđan POPOV[1]

[1]Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

Abstract

This research presents an analysis of spatio-temporal distribution of fire occured in multi-storey residential buildings in Novi Sad, in the period from 2011-2013. The analysis includes basic indicators of frequency, time and place of fire occurrence in these buildings.

Collected and analyzed statistical data was transformed in the fire hazard map by using QGIS, a free and open source Geographic Information System, which enabled futher research and more liable data as well as easy data sharing with authorities and residents. Based on these results, city areas with the most frequent fire events were identified and the Fire department was able to organize educational drills in targeted urban areas and buildings.

Keywords: *residential fires, spatiotemporal analysis*

1. INTRODUCTION

Statistics on fires provide valuable information that can greatly aid in understanding the causes and consequences of fires. The given data can be used to raise awareness about fire hazards, as well as to develop and implement appropriate measures that would improve the current state of fire safety (Supic et al., 2015).

Of the 5 million fires that occur worldwide each year, as many as 75-80% happen in residential buildings, resulting in the death of 40,000 to 50,000 people. In addition to direct exposure to flames, fatalities also occur due to inhalation of toxic combustion products or as a result of structural collapse in buildings that do not have sufficient resistance to fire (Milanko, 2015).

Fire poses a significant danger to life and property in both urban and rural areas. The risk of fire in residential buildings is particularly high, primarily due to the large number of occupants (Laban et al, 2017). According to testimonies from fire brigades, as much as 80% of all fires are caused by human negligence. The most common causes of fires are improper handling of electrical devices, inadequate maintenance of devices, installations, and equipment, and incorrect use of fire. High-rise residential buildings present an additional problem, as evacuation from them is very difficult, leading to loss of life.

Within the study, the spatial-temporal distribution of fire hazards that occurred in Novi Sad during the period from 2011 to 2013 was presented using the Quantum Geographic Information System (QGIS). Based on the presented results, statistical data were derived, indicating urban areas with the most frequent fires. The analysis included basic indicators of the frequency, timing, and location of fires in multi-story residential buildings.

The obtained results should be considered even in the design phase of buildings, as some statistics are truly alarming.

2. FIRE SAFETY INDICATORS AND FIRE RISK IN THE REPUBLIC OF SERBIA

There is no absolute safety because there is always a risk. If the probability of a hazardous event occurring is extremely low, or if the potential consequences are minimal, the risk is considered acceptable. Calculating the risk of fire hazards is very difficult because once a fire starts, its behavior cannot be predicted, as it depends on many factors.

Past experiences indicate that statistical analysis of fires in the Republic of Serbia has not been applied adequately. Until 2009, statistical data on fires in the Republic of Serbia were generally not collected appropriately. Organizational units dealing with preventive protection significantly presented data only on fires investigated (i.e., fires with casualties, injuries, or significant material damage). These were the official data submitted to the Administration for Analytics of the Ministry of Internal Affairs, collected from regional organizational units.

Operational units (formerly fire brigades, now firefighting and rescue units - FRU) reported on fires they intervened in. However, fires extinguished by members of volunteer fire departments (VFD), industrial professional fire units, or citizens were not always recorded (only a very small number were reported and recorded using specific forms), and their statistical data were not presented as official data on the number and type of fires (Baras et al., 2009).

Acceptable indicators of fire safety and fire risk, based on statistical data, are not defined by regulations in the Republic of Serbia, so conclusions can only be drawn by comparison with other countries. The Fire Protection Law of the Republic of Serbia was adopted in 2009, and upgraded in 2015 and 2018. Alongside the law development, a program for recording fires and other events under the jurisdiction of the Emergency Situations Sector was initiated.

The new program introduced the obligation to record fires regardless of who intervened (professional FRU, volunteer fire unit - VFD, industrial fire unit, or citizens). For fires where professional FRUs did not intervene, reasons must be stated (e.g., lack of notification, inability to reach the fire site due to inaccessible terrain, lack of roads, etc.).

Based on the research of global fire statistics (hereinafter CTIF), there were 17,304 fires in the Republic of Serbia in 2010, resulting in 311 injuries and 81 fatalities.

Table No. 1 shows the trend of fires and the number of casualties in the Republic of Serbia for the period from 2006 to 2010, based on CTIF research.

Table 1- Trend of fires and the number of casualties in RS (2006-2010)

Year	2006	2007	2008	2009	2010
Number of fires	5712	6948	6673	6168	17304
Casualties	89	86	93	86	81

In the development of the Fire Protection Strategy for the period 2012-2017, an assessment of the situation in the Republic of Serbia was conducted, identifying many deficiencies that affect the ability to rescue and extinguish fires, particularly in residential buildings:

- Many buildings are constructed near residential areas without protective zones relative to nearby structures, with limited storage space and inadequate access for fire vehicles.
- The transportation infrastructure is unsatisfactory.
- There is insufficient preparedness of fire protection entities for implementing preventive measures.
- Access to most multi-story residential buildings is difficult or impossible due to an inadequate road network.
- Electrical and chimney installations are improperly maintained, and fire-fighting equipment and resources are damaged or stolen.
- The capacity of the public water supply network is inadequate.

- Citizens' safety culture is insufficient.
- Firefighting and rescue units are inadequately staffed with qualified, skilled, and physically and psychologically capable human resources for protection tasks.
- The number of firefighters and rescuers is below European standards.

Since then, almost nothing has been done to improve fire safety. Serbia, in addition to having a number of firefighters below the European average, is very poorly equipped, mostly with outdated equipment.

What Serbia leads in is the area in square kilometers covered by a single fire station, which amounts to 169.8 km², more than ten times larger than the area covered by a fire unit in London, and even 50 times larger than in New York (CTIF, 2015).

The city of Novi Sad had 108 firefighters forming a brigade 30 years ago. Today, when Novi Sad is larger and more developed, the Novi Sad Fire Brigade counts only 95 firefighters, although the actual need is for 155. This creates a significant problem for their efficiency, as successful and rapid fire extinguishing also depends on the number of people involved. In one shift, only 21 firefighters are on duty, and a major issue is that they are located in only one building, in the city center (FUS, web page).

3. NOVI SAD CHARACTERISTICS

Regarding the age of apartments, Novi Sad, along with Subotica, is one of two cities in Serbia with over 10,000 apartments built before 1946, but it is also one of three cities in the Republic of Serbia with over 10,000 apartments built after 2001.

The area of Novi Sad has historically been attractive for settlement due to its favorable geographic location. The population growth in the city has been recorded throughout the entire post-war period, with some periods experiencing very intense growth. This increase was more significantly influenced by mechanical influx rather than natural growth.

The most intense demographic growth in Novi Sad occurred during the period from 1961 to 1971, when the population increased by about 37%.

The oldest urban districts of Novi Sad are Stari Grad and Podbara (Almaški Kraj). By the mid-19th century, as the city expanded westward, Rotkvarija, Salajka, and Grbavica emerged. Older parts of Novi Sad also include the former separate settlements of Sremska Kamenica, Petrovaradin, and Klisa, which are now part of the city's urban area. By the mid-20th century, urban districts such as Banatić, Sajmište, Adamovićevo Naselje, Telep, Stara Detelinara, Liman 1, Vidovdansko Naselje, Slana Bara, Mali Beograd, Stari Šangaj, and others were established.

Modern buildings and wide boulevards were constructed in Limani (Fig. 2), Novo Naselje (Fig. 3), and Detelinara, which are also the three largest neighborhoods in Novi Sad by population. These neighborhoods were built due to the large influx of population after World War II, on areas that were once forests and fields (Laban et al., 2017).

Figure 1 – Urban Districts of the City of Novi Sad

Figure 2 – Liman area

Figure 3 – Novo Naselje area

Many old houses in the city center, in Rotkvarija, and around what is now Bulevar Oslobođenja were demolished during the 1950s and 1960s to be replaced with multi-story buildings. The city experienced a new construction boom at the end of the 20th and the beginning of the 21st century, during which the largest number of multi-story residential buildings were constructed. Some older urban districts, such as Grbavica, Stara Detelinara, and Telep, have completely changed their appearance. Novi Sad is a typical Central European city, with only a few buildings constructed before the 19th century. Since the old Novi Sad was destroyed during the revolution of 1849, the city center is dominated by 19th-century architecture (Novi Sad, web page).

In the past, the area around the city center predominantly had single-story houses, which is why ground-level apartments are the most common. Among other things, there are two types of characteristic urban residential blocks: detached buildings dating from 1960 to 1990 (about 40%) and enclosed residential blocks (row houses) built in a traditional style, constructed after 1990 (50%) (Laban et al., 2017)

According to data from the Republic Institute for Statistics (web page), the share of people aged 65 and older in the total population of the Republic of Serbia is 17.4%, while the share of those under 15 years old is 14.3%, indicating that the country is in an advanced stage of demographic aging.

According to the 2011 census data, the city of Novi Sad has a population of 341,625, with 250,439 residents living in the city itself. Based on data from the Republic Institute for Statistics, 56% of households consist of one or two members, while the average number of members per household is 2.61 people. In Novi Sad, the total number of residential units is 144,631, of which 114,451 are occupied residential units, while the rest are temporary or abandoned. The largest number of residential units (101,542) consist of three or more apartments, classifying them as apartment buildings. The number of residential units with two apartments is 8,668, while the number of residential houses is 34,105.

4. DATA COLLECTION METHODOLOGY

The process of collecting spatial data requires significant costs, but if they exist in digital form, they can be easily reproduced and distributed because values are assigned to them, and they can be simply merged and combined with other information. The ability to display a large amount of spatial data stored in a computer's memory in a visual, simple, and user-friendly format is the main advantage of GIS over other technologies.

Geographic Information Systems (GIS) technology has become an important part of managing disasters around the world. By providing detailed models of geographical features combined with analysis of various geographic layers, GIS enables us to identify areas at high risk for natural disasters and formulate plans for mitigating them before they occur. Also, these technologies help people make important decisions during emergency response operations by giving them real-time information about ongoing relief efforts and possible risks in certain areas or disaster zones.

A typical example of these systems is QGIS, a free software application that allows for the viewing, editing, and analysis of geospatial data. These information systems are most often connected to most related databases (such as geodetic, geological, hydrological, mining, agricultural, forestry, and urban planning databases), as well as databases related to census data, statistical data, technological databases, and databases concerning health, education, culture, and other demographic characteristics.

In order to bring a statistical dataset into a spatial context using QGIS, it is necessary to create a vector representation that reflects the real environment. For example, if we want to associate spatial data with information on the number of fires in Novi Sad from 2011-2013, it is necessary to: display the area of interest using the appropriate geometry (polygon, point, line), and define attributes that best describe the area of interest in accordance with the research needs.

Maps can be significant tools through which information about hazards, vulnerabilities, and risks in a specific area are displayed, thus supporting the process of risk assessment and the overall risk control strategy. Maps also play an important role in ensuring that all stakeholders in the risk assessment process have the same information about hazards, as well as in communicating the results of the risk assessment to interested parties. Risk maps provide numerous opportunities for considering various effects that may not be obvious when it comes to an individual hazard. A minor hazard in one area may cause a significant hazard in another, or low losses with a high probability of occurrence in each unit could become very unfavorable in their entirety. For these reasons, risk maps can help determine priorities for risk mitigation strategies.

QGIS can be defined as a powerful set of tools for collecting, storing, accessing, transforming, querying, and displaying spatial data from the real world for specific purposes. The application of QGIS in spatial planning is indisputable. Thus, its ability to transform spatial data into relevant information represents its core value and advantage. Considering that the use of QGIS, as an organized set of computer hardware, software, data, personnel, and networks, enables the recording, editing, management, handling, analysis, modeling, and display of data with spatial reference, as well as storage in one place, its implementation is seen as a more appropriate solution.

When observing any GIS project, it is possible to notice that it consists of several layers or types of features. Depending on what is to be presented on them, the layers can be arranged in any order (Fig. 4), with each layer being connected to an attribute table. Furthermore, alphanumeric data attributes are linked to objects and locations, where by selecting any object, the data becomes visible and subject to analysis.

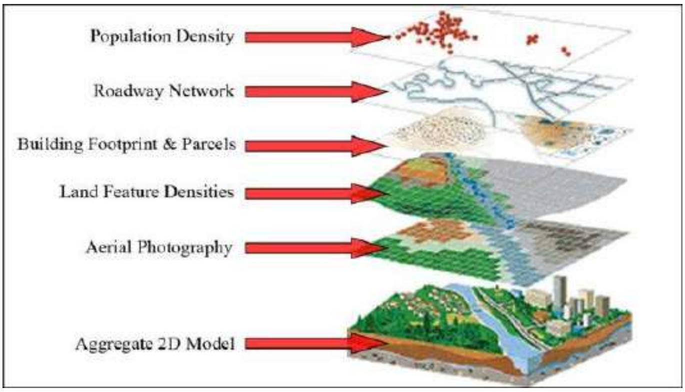

Figure 4 - GIS layers image (Goldstein, 2010)

Since QGIS represents a simulation of the real environment, it is primarily illustrated with various layers, within which data are organized according to appropriate criteria. Some of the layers in QGIS include the address register, city zones, cadastral maps, orthophotos, and more.

The importance of QGIS in modern society is growing, primarily due to the development and application of information and communication technologies that contribute to its more efficient use, as well as future development. The GIS industry encompasses a wide range of application possibilities. This will increase over time through technological innovations, the development of awareness about its advantages as a powerful decision-support tool, and greater availability of spatially represented data and software. The power of QGIS lies not only in its ability to visualize spatial relationships but also in its creation of a holistic view of the world that arises from its interconnected components and complex relationships. The QGIS database is used to store exclusively geographical data (e.g., terrain slopes, locations of roads, rivers, etc.), as well as all other relevant information relating to the geographic location of fires, land characteristics, water sources, tourist route positions, etc. In the case of a fire, these data can be very useful for predicting fire spread and also for planning the firefighting efforts (Indzic et al., 2013).

5. ANALYSIS OF THE SPATIOTEMPORAL DISTRIBUTION OF FIRE

The analysis began with the introduction of the map of the area under investigation. For the purposes of the research conducted in this paper, the map of Novi Sad was imported into the QGIS project (Fig. 5).

In order to geolocate fires in residential buildings on the map of Novi Sad, a total of 20 layers were created, with each residential building where a fire occurred assigned the following attributes:

- Street and building number where the fire occurred,
- Number of evacuated people, by the fire brigade in Novi Sad,
- Number of injured or deceased individuals in the specific fire and
- Type of equipment used to extinguish the specific fire.

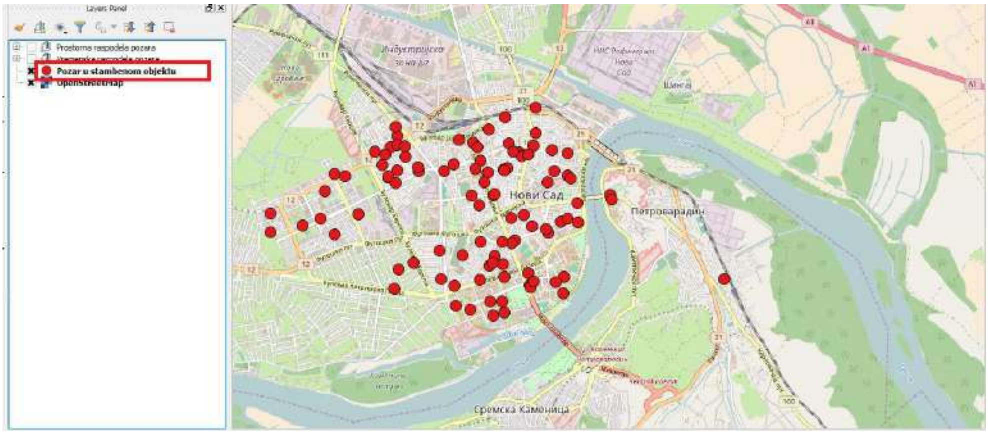

Figure 5 – Fire events in multi-story residential buildings in Novi Sad in 2011

The main layer contains all the fires recorded on multi-story residential buildings during one year in Novi Sad, while the other 19 layers are grouped into two main groups related to the temporal and spatial distribution of fires.

Within the group related to the spatial distribution of fires, two subgroups were created to define the location of the fire origin:

- In the building – depending on whether the fire occurred in the ground floor, basement, elevator, roof, or floor
- In the apartment – depending on whether the fire occurred on the terrace, hallway, bathroom, living room, or kitchen.

Within the group related to the temporal distribution of fires, three subgroups were created to define the time of the fire occurrence:

- Season – depending on whether the fire occurred in autumn, summer, spring, or winter
- Time of day – depending on whether the fire occurred at night, in the afternoon, or in the morning
- Day of the week – depending on whether the fire occurred on the weekend or during a workday.

By overlapping different layers in accordance with the research interest it is possible to generate a number of spatiotemporal fire distributions (e.g. fires in the kitchen, 3rd floor apartments, during afternoon on Wednesday in the summer).

During three years (2011-2013), in Novi Sad 2939 fires were recorded: 366 in multistorey apartment buildings (12.5%). The majority of fires started at upper floors (74%) and ground floor (24%), while a rather small number of fires occurred in the basement, roof or elevator.

One of the reasons for an increased number of fires in the ground floor were electrical installations (distribution cabinet malfunction) or arson (advertising flyers were set on fire), as it was concluded after further analyses.

5.1 Spatiotemporal distribution of fires in Novi Sad in 2013

In 2013, there were 793 fires recorded in Novi Sad, of which 152 occurred in residential buildings, making up about 20% of the total number of fires. Fire hazard map for apartment buildings in Novi Sad, in 2013, is given in Fig. 6: fires were more frequent in the urban areas of Liman, Detelinara, Banatić, Rotkvarija, and Stari Grad, while there were almost no fires in Telep and Sajmište.

Of the total number of fires in 2013 in the territory of Novi Sad, about 66% (98) occurred on the upper floors, while the remaining 34% (54) were in the basement, ground floor, elevator, or attic/roof. One of the reasons for fires in the basement is that basements are often used to store unnecessary and useless items, which is essentially a bad habit. Many flammable items and materials make this part of the building extremely fire-prone. Common items found there include old paper, cardboard, textiles, old furniture, various paints, sprays, and varnishes, most of which have even expired, and their combustion products can be extremely toxic. The situation is similar in attic spaces. Therefore, it is essential to keep the basement clean and in order, removing unnecessary items and easily combustible materials.

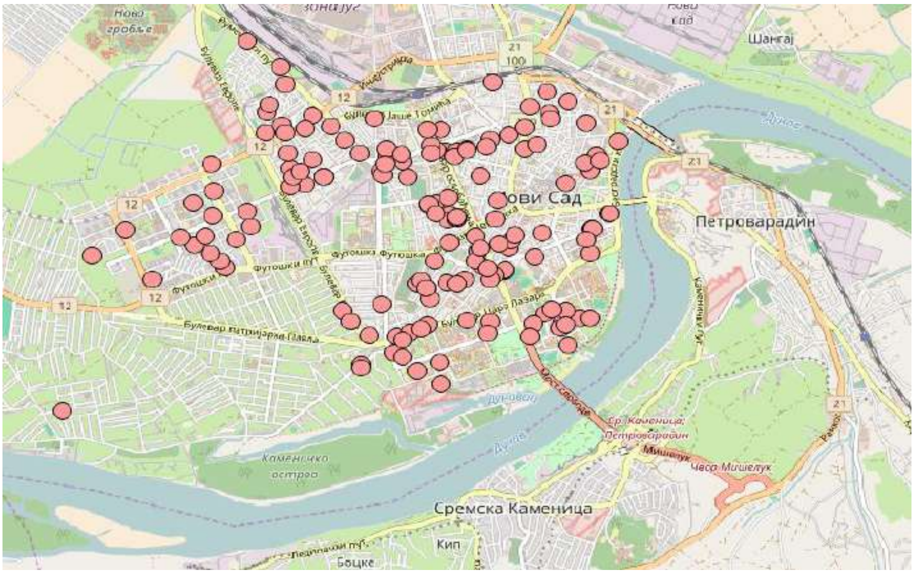

Figure 6 – Fires in apartment buildings in Novi Sad, 2013

Spatial fire distribution in 2013, based on the place where the fire started in the apartment, is shown in Figure 7.

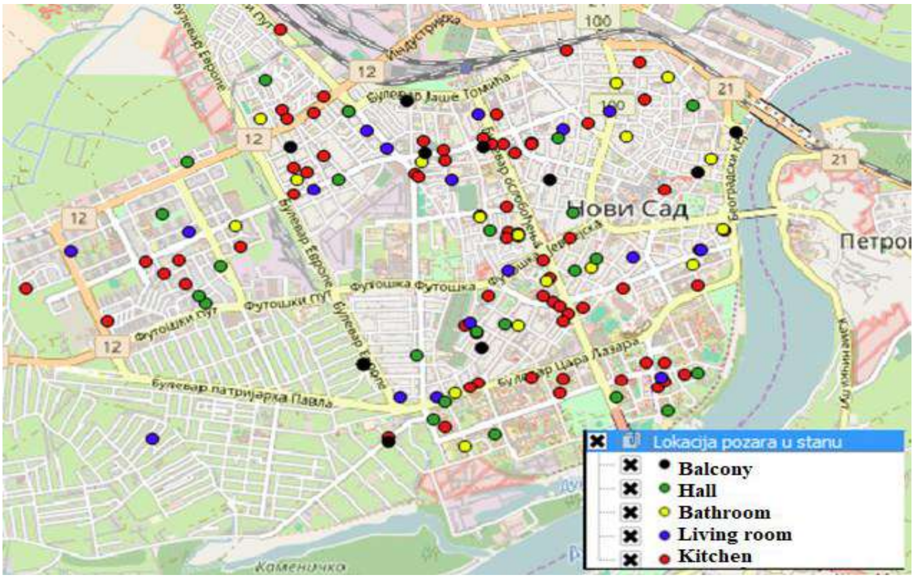

Figure 7 – Fire event distribution in apartments in Novi Sad, 2013

In terms of the location of the fire within the apartment, the kitchen is the most critical area, with 49% (69) of fires occurring there, while the remaining 51% happened in the hallway, living room, bathroom, and terrace. The smallest percentage of fires originating in the kitchen occurred in the city area of Rotkvarija, while nearly 50% of the fires in the city area of Novi Naselje started in the hallway. The most common cause of fires in the hallway is malfunction of an electrical distribution cabinet.

In European countries where fire cause statistics are available, it has been determined that electrical system faults account for 15–20% of all fires (Hadziefendic, 2008). According to the same statistics from 11 European countries (Bulgaria, Czech Republic, France, Hungary, Italy, Poland, Romania, Russia, Turkey, and Ukraine), between 1988 and 1998, the number of fires caused by electrical system faults increased by 25%, and there is a tendency for this to continue growing. Interestingly, during the same period, the increase in fires caused by non-electrical causes was only 5%.

Statistical data on the locations where electrical system faults, resulting in fires, occurred include the following:

- Faults in conductors installed in the building (over 33%),
- Cables and plugs (close to 20%),
- Bulbs and various light sources (close to 20%),
- Switches, extension cords, and outlets (over 10%),
- Fuses, main switches, distribution boards (around 5%),
- Measuring devices and their housings,
- Energy transformers and
- Other locations within the electrical distribution system.

Regarding the season in the year, most of the fires started in winter and spring (Fig. 8), more fires occured in working days than during weekends and in the afternoon and during the night.

Most of the fires occurred in the spring, accounting for 29% (44) of the total number of fires. The same number of fires were recorded in autumn and summer, each at 25%, while the smallest number of fires occurred in winter, with 21%. Fires in winter were not as frequent as in the previous two years (2011, 2012). One reason for this could be that 2013 was one of the warmest years since 1850[1]. In the areas of Stari Grad, Detelinara, and Bistrica, there were almost no fires in winter, whereas they were an extremely frequent occurrence in the city areas of Grbavica and Liman during 2013.

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[1] This observation is supported by data from various meteorological organizations, including the World Meteorological Organization (WMO) and the National Oceanic and Atmospheric Administration (NOAA), which noted that global temperatures in 2013 were significantly above the 20th-century average.

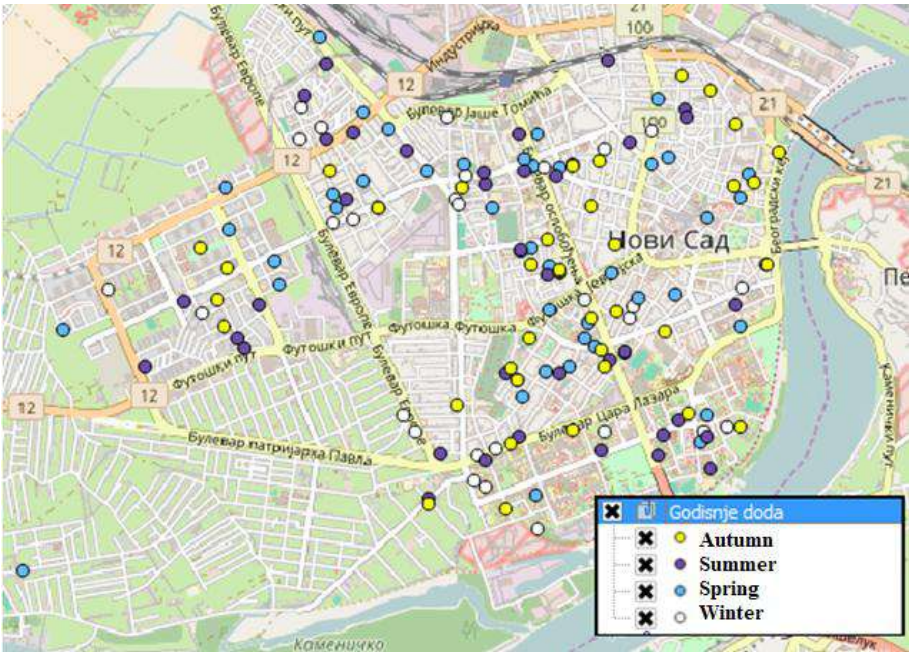

Figure 8 – Fire event distribution according to season in Novi Sad, 2013

Fires are more frequent in the afternoon and at night, each accounting for 38%. Fires occur more frequently on weekdays than on weekends, with a share of 76% of the total number.

5.2 Comparative analysis of fire events in Novi Sad 2011 -2013

Based on the conducted analysis of the spatial-temporal distribution of fire hazards, it can be concluded that the number of fires in high-rise residential buildings in Novi Sad has increased over the researched three years (Fig. 9).

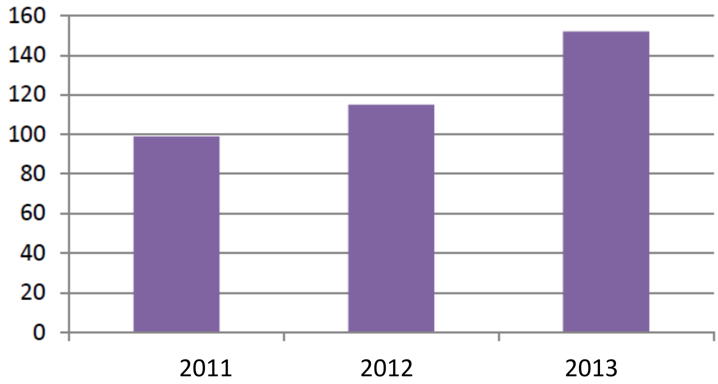

Figure 9 – Number of fire events in multi-story residential buildings in Novi Sad, 2011 - 2013

Most apartments, 90%, in Novi Sad have central heating installations, so chimneys are not used in residential buildings. Fires usually start due to old and poorly maintained electrical installations.

The fire brigade arrives in less than 10 minutes at any location within the city area. According to statistical data on fires in residential buildings, it is most common for a fire to start on the ground floor, and it is twice as likely to start on any other floor. Fires rarely occur on the roof, attic, or loft (Fig. 10).

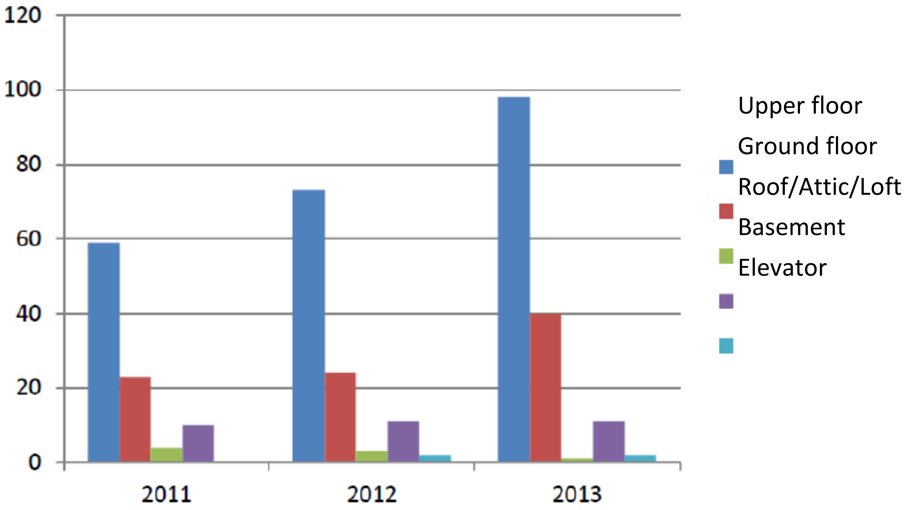

Figure 10 – Number of fire events in multi-story residential buildings in Novi Sad, 2011 - 2013

Based on the data from the U.S. Fire Statistics (USFA), the most common cause of fires in the United States is cooking, which is responsible for 50% of all fires that occurred in 2014. Fires caused by cooking or heating are usually visible right from the start, while fires that occur in electrical installations are "hidden from human sight" in the initial stages of development.

The kitchen is also the most often place where fire started in multi-story residential buildings in Novi Sad in 2011 -2013 period (Fig. 11).

The most of the fires occurred during the winter season, following by spring period (Fig. 12), while almost the same number of fire events happened in the afternoon and during the night (Fig. 13). Also, aproximetly three times more fires started during working than weekends (Fig. 14).

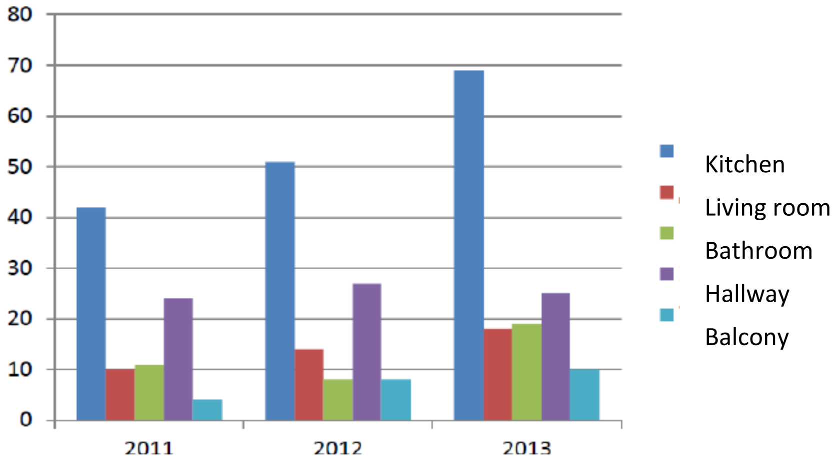

Figure 11 – Number of fire events in multi-story residential buildings, based on the place of occurence in the apartment, in Novi Sad, 2011 - 2013

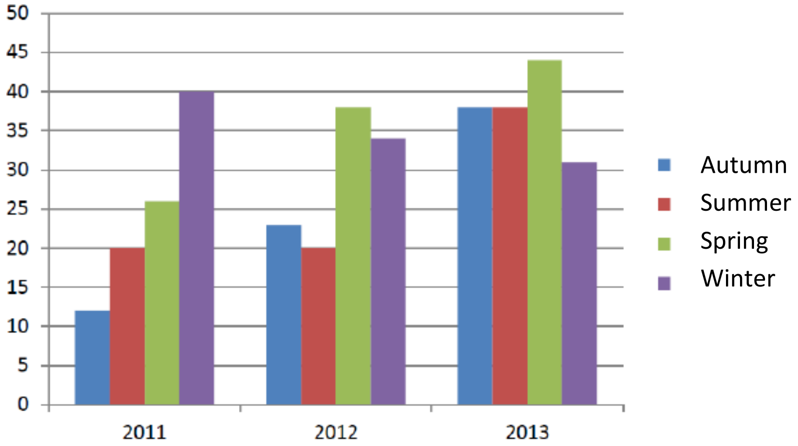

Figure 12 – Distribution of the number of fires in multi-story residential buildings, depending on the seasons, in Novi Sad, 2011 – 2013

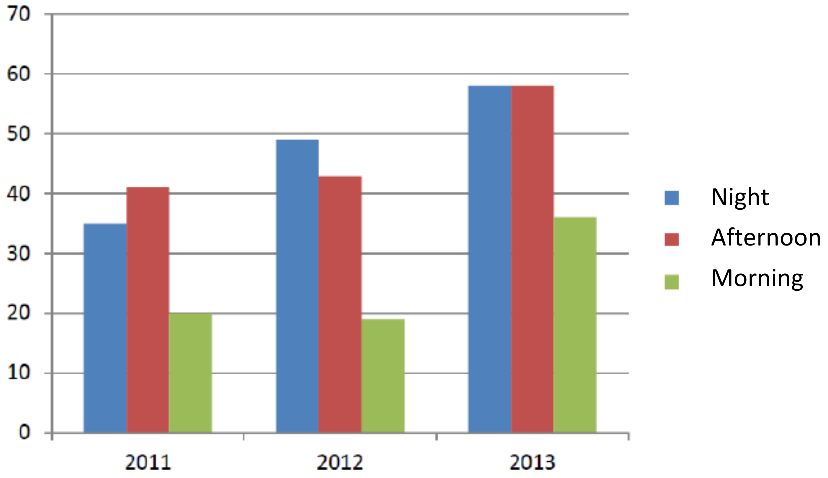

Figure 13 – Distribution of the number of fires in multi-story residential buildings, depending on the seasons, in Novi Sad, 2011 - 2013

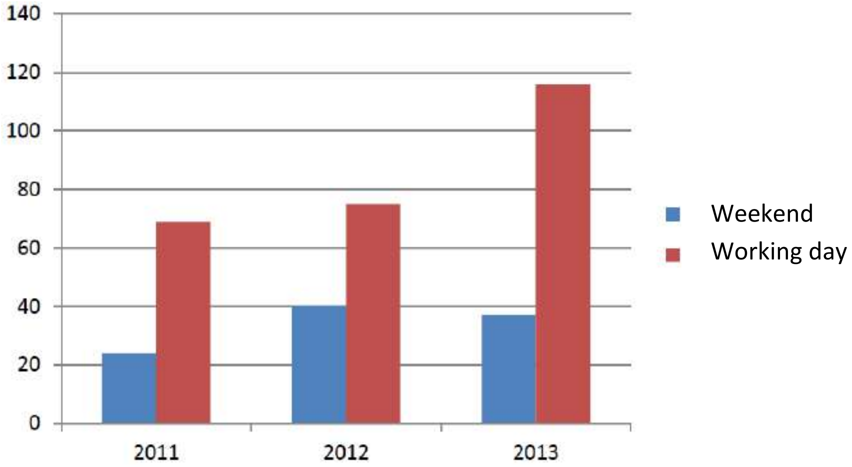

Figure 14 – Distribution of the number of fires in multi-story residential buildings, depending on the seasons, in Novi Sad, 2011 - 2013

6. DISCUSION OF RESULTS AND CONCLUSION

The study performed an analysis of the spatial-temporal distribution of fire hazards in multi-story residential buildings in Novi Sad, which occurred between 2011 and 2013.

The conclusions drawn from the collected and processed statistical data on fire occurrences during the three-year period (2011-2013) indicate a steady increase in the number of fires in multi-story residential buildings, which are taking up an increasing percentage of the total number of fires.

In terms of the location of the fire's origin within the building, the largest number of fires occurred on the one of upper floors, followed by the ground floor. One of the reasons fires occur on the ground floor is due to faulty electrical cabinets, as well as the intentional ignition of paper, cardboard, or advertising materials.

Regarding the origin of the fire within the apartment, the highest number of fires between 2011 and 2013 occurred in the kitchen, followed by the hallway, bathroom, living room, and balcony. The largest number of fires in the kitchen occurred because most of the electrical appliances are used for food processing and preparation. The second most common fire origin point in the apartment was the hallway, where electrical fuses are generally located, making them the most frequent cause of fires.

Depending on the season, fires were most frequent in winter, during the heating season. Causes include faults in installations, malfunctioning heaters, drying clothes on radiators, decorative candles, or lanterns left unattended. Additional risk factors include the age of the residents and the distance of fire-fighting units from residential buildings. The combination of all these factors can cause significant damage, injuries, and even loss of life.

Regarding the time of day when fires occurred in multi-story residential buildings, fires were most frequent at night and in the afternoon, with the fewest fires occurring in the morning hours, when fewer people are in the apartments. In other words, the risk of fire increases as the number of residents in buildings increases.

By analyzing the spatial distribution during the period from 2011 to 2013, it was noted that the safest area, with the fewest high-rise residential buildings, was Telep. It was also observed that fires were less frequent in the areas of Satellite, Bistrica, and Novo Naselje. This is due to the lower population density in those areas, even though there are residential buildings, they are not as numerous as in the most fire-vulnerable areas (Detelinara, Rotkvarijum, Liman, Sajmiste).

One of the reasons may be that during fire interventions, firefighters encounter a number of problems. When leaving the fire station, their path is often blocked by cars parked in front of the garage, even though there are signs prohibiting parking and stopping. There is also inadequate driver behavior in traffic, as many drivers do not yield to fire trucks with sirens on. Furthermore, the question arises about how well residential buildings are equipped with fire-fighting equipment and how well residents are trained to handle it. Residents are mostly not trained to act in the event of a fire and do not know how to behave when a fire occurs. Surely, at some point, you’ve returned halfway from home because you were unsure whether you had turned off the stove, the burner, or the iron, and you went back to check. Sometimes you had a good reason to return, and sometimes you didn’t, but you always did the right thing because in our city, the most common cause of fires is leaving a heating appliance turned on at home. And the damage caused by fires can be catastrophic.

Such analyses can be significant because they provide information on hazards, vulnerabilities, and risks in a particular area, thus supporting the risk assessment process and the overall risk control strategy. Spatial temporal analysis and GIS based interactive hazard maps and models are the starting point for in depth fire risk research, providing accurate and valuable information on hazards, vulnerability and support risk mitigation and management.

Above all, it is necessary to work on raising awareness about the importance of fire protection through education in schools, the employment of household councils, and the active participation of all residents in evacuation drills that should be carried out by the Firefighting and Rescue Service.

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