Understanding Fire and Protecting the Buildings

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ABSTRACT **To achieve effective protection of a building, it is necessary to understand fire as a complex physical and chemical phenomenon. This work describes the aspect of the uncontrolled combustion process, the conditions and probability of combustion formation, the basic parameters of fire within certain development phases, and its dynamics in time and space. However, to understand the combustion process itself is not enough for successful fire control and thus for avoiding material damage and threats to human safety. In this regard, this work indicates what active and passive fire protection measures are necessary in the building planning process, and, using the example of the Republic of Serbia, reviews laws and regulations, thereby providing a basis for understanding the content and structure of the integral building fire protection project.**

KEYWORDS fire, risk, fire phases, fire parameters, building protection, active and passive measures

1 Introduction

The development of new technological processes and techniques; utilisation of flammable materials; new building materials, elements, and components (Meacham, Poole, Echeverria & Cheng, 2012); existing building heritage (Bernardini, 2017); a number of external social, economic (Jennings, 2013), and environmental (Crichton, Nicol, & Roaf, 2009; Kolbert, 2016; California Department of Forestry and Fire Protection, 2017) factors and causes; and the concentration of material assets in a small area, inevitably carry a danger for the occurrence of fire in buildings. It is, however, certain that the appropriate measures can reduce the number of fires, as well as the extent of their consequences. Taking measures means engaging appropriately in the carrying out of a wide range of activities, not only by the bodies that have jurisdiction over fire protection, or professionals and experts, but also by every subject participating in the processes of design, construction, and utilisation of buildings, equipment, and devices.

Considering that it is not possible to predict where and when a fire will happen, in recent years, there have been great scientific research efforts to understand the processes of occurrence, development, and spread of fire so that a comprehensive set of knowledge has resulted in the emergence of a new engineering discipline called fire engineering. Fire engineering offers more advanced methods of predicting the development of fire and its impact on buildings (Purkiss, 2007).

Fire protection includes a set of organisational-technical activities that can be grouped into preventive, repressive, and sanctioning measures. The realisation of effective preventive protection requires a high degree of knowledge about the basic concepts and definitions of uncontrolled combustion processes, as well as the conditions and probability of their formation.

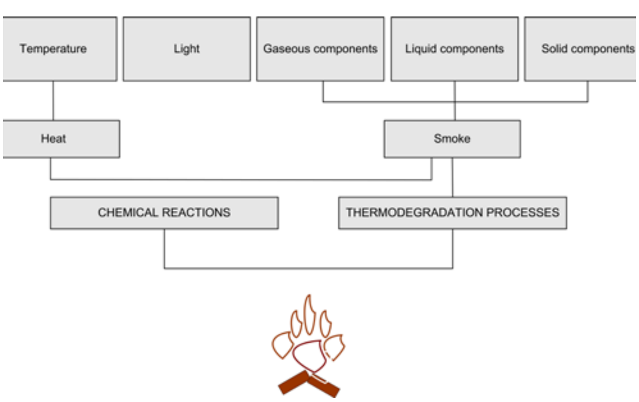
2 Basic Concepts and Definitions of Fire

Every year, about 2.5% of residential buildings worldwide are damaged or destroyed due to the occurrence of fire. The casualties in fire events are not caused only by flame and smoke, but also from the devastation of structures that are not capable of withstanding escalated high temperatures. The research into the emergence and development of the combustion process began in the 17th century, when the interest in finding ways to control fire was born. In order to reduce the risk by undertaking preventive measures, scientists investigated possibilities to predict fire occurrence. It is known today that preparatory (preventive) fire protection measures must be embodied in a building design before the construction process starts (Bisby, Gales, & Maluk, 2013).

Unlike widely elaborated, controlled combustion, this work hereinafter focuses on uncontrolled combustion processes known as fires. A non-stationary combustion process that takes place in time and space is at the basis of the fire. In general terms, the conditions for the occurrence of an uncontrolled combustion process can be divided into necessary and additional conditions.

Necessary conditions are the presence of flammable matter, oxidising agents and ignition sources. However, the fulfilment of these conditions does not necessarily mean that combustion will start. For instance, flammable materials (furniture, clothes, etc.) and oxidisers (oxygen from the air) are always present in residential buildings, and often the ignition sources (such as the flame of a lighter or matches, heated stove plates, flame gas stoves, etc.), but the fire rarely occurs. To create a fire, it is necessary to provide *additional conditions* caused by the physical and chemical properties of the combustible matter, characteristics of the ignition source, nature of the oxidiser, and other factors. This means that the basic principle in preventive fire protection must be based on the exclusion of the additional conditions necessary for the formation of the combustion process.

Every fire is followed by the formation of gaseous, liquid, or solid combustion products, and the release of heat and light emissions (Fig 2.1). Chemical reactions and thermodynamic processes occurring during a fire event depend on the composition of combustible material. When a gas burns, there is only a chemical reaction. However, when free gas mixtures and solid substances are burning, thermodegradation processes are also present. As a result of the chemical reactions and thermodegradation processes, heat is released. Subsequently, the temperature in the combustion zone and the surrounding environment is increased, the light is emitted, and the products of combustion are formed.



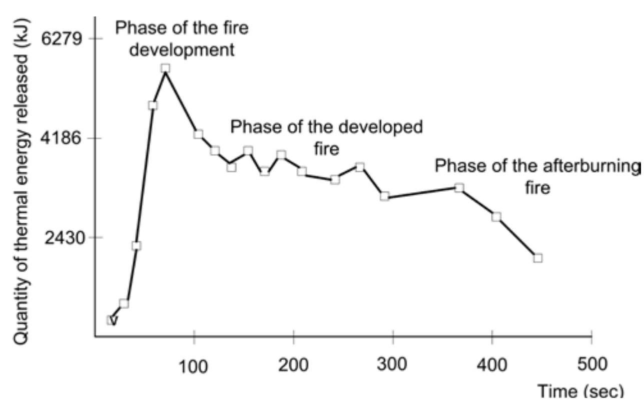


FIG. 2.1 Reactions and processes following the fire occurrence

FIG. 2.2 Fire development stages

The fire *hotspot* is a space, i.e. the area of the most intense combustion. Hotspot performance is influenced by the presence of flammable substances, the continuous inflow of air, i.e. oxygen, and the continuous heat release necessary to maintain the combustion process. Disruption of any of these conditions results in combustion termination.

Fire hotspots are a relative term. In the initial stage of development, the fire focus is on small part of the room or on some objects within that room (initial hotspot). If the fire has spread to the whole building, the hotspot may be the room initially affected.

The fire development process is viewed through three characteristic phases (Fig 2.2). The *fire growth phase* is characterised by the continuous expansion of the initial fire source, catching over 80% of present flammable material. The *phase of fully developed fire*, after reaching the maximum burning rate of the present mass fire load, is characterised by the constant presence of the flame and constant burning of the mass. The *decay phase* is characterised by a rapid reduction in the burning rate of still unburned combustible materials and elements of building structure by smouldering.

Any uncontrolled combustion is followed by the appropriate distribution of gas fractions of the room of fire origin and surrounding environments. In an enclosed space, the inflow of external air to the combustion zone and the removal of formed gaseous combustion products are achieved through the openings, i.e. as a result of a difference between internal and external pressure. The pressure of combustion products in the upper parts of the room is higher than the atmospheric pressure, while it is lesser in the lower layers. At a certain height, the pressure inside the room is equal to the atmospheric pressure, i.e. its difference is zero. The surface of equal pressures is called a neutral zone or plane. In the case of indoor fires (Section 3), the process of exchanging masses of gaseous fractions and the position of the neutral plane are conditioned mainly by the position, height, and volume of the room, as well as the number and position of present openings (e.g. doors, windows, ventilation openings, etc.). In addition to the aforementioned existing conditions of exchange of mass fraction of gaseous fractions, the fire duration and thus its thermal effect on structure and technologies are also conditioned by present fire load.

Thermal fire load is the value of total heat energy that can be freed from the combustion of the combustible material present in the room or open space (SRPS U.J1.030: 1974). The fire load also includes the inflammable structural elements of the buildings.

All flammable substances in the room and those incorporated in the building structure are understood as the *mass fire load*. Depending on the layout of the mass fire load, all rooms, regardless of the purpose, can be divided into two groups. The first group consists of rooms in which the mass fire load is located in one or more parts of the floor area. In this case, combustion takes place only in certain parts of the floor space, not generating the general zone of gasification and combustion of materials. The second group includes rooms in which the mass fire load occupies a larger part of the floor area, so combustion occurs on the entire surface producing the general zone of gasification and combustion of materials.

Every fire occurs on a certain surface, i.e., in a certain area that is conditionally divided into combustion zone, thermal action zone, and smoke zone. Precise limits between these zones cannot be drawn.

The *combustion zone* coincides with the volume of the flame torch in which the processes of thermal decomposition of solid flammable substances, evaporation of liquids, and the combustion of gases and vapours are ongoing. In an enclosed area, the combustion zone is usually limited by the building structure. The combustion zone is linked to the *thermal action zone,* characterised by the heat exchange between surfaces of the flame and surrounding environment, flammable material, structure, etc. (Drysdale, 2011). The heat exchange between the fire source and the surrounding environment is achieved by conduction, convection, and radiation (Fig. 2.3).

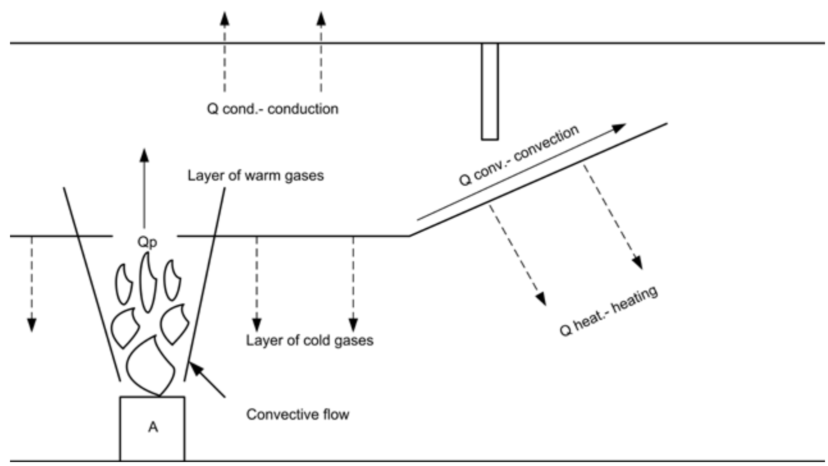


FIG. 2.3 Heat exchange between fire hotspot and surrounding environment

In the initial phase of indoor fire development, transfer of the heat from affected to adjacent rooms is done by conduction through the building structure and components. Until the moment of intense smoking, radiation is the primary mode of spreading the heat from flame surface to affected surrounding space. After a certain degree of smokiness is reached, flame heat radiation is weakened. In developed indoor fires, heat transfer by convection is more emphasised than in open space.

Smoke is a dispersive system of gaseous, liquid, and solid combustion products, generated by the decomposition of flammable matter. Due to the content of certain toxic substances, smoke has a harmful effect on human health. Furthermore, smoke reduces visibility, causes feelings of disorientation in the space, has certain corrosive properties, etc. *Smoke zones* formed by fire have their own characteristics. The extent of the smoke zone in a room affected by fire is conditioned by the physical and chemical characteristics of fire-affected flammable substances, expansion of combustible products, and mass exchange of gaseous fractions with the outside environment. Combustion products rise in the form of convective currents above the combustion zone, and form a smoke layer in the upper part of a room (below the ceiling). As a result of the adequate pressure increase, fire heated electricity combustion products flow through different passages and openings into the external environment or adjacent rooms.

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3 Fire Classification

A fire can be classified according to the place of occurrence, material resistance during combustion, development stage characteristics, and the heat emission velocity (Fig. 3.1).

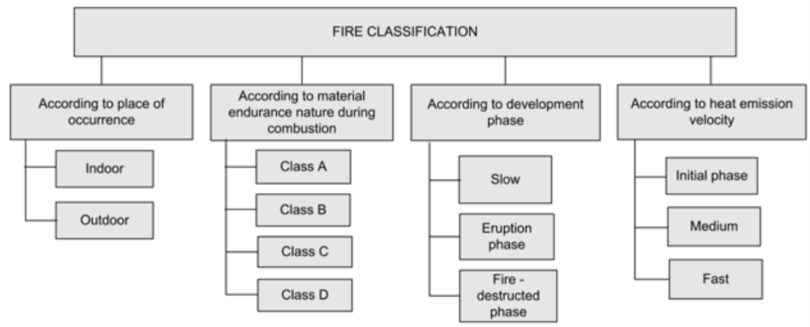

FIG. 3.1 Fire classification

3.1 Indoor Fires

An indoor fire is one that develops in an enclosed space, in one or more premises of a building. Under certain conditions, indoor fires may be converted into outdoor fires. This most often occurs when parts of a building are destroyed in fire, or when a flame reaches the external environment.

Indoor fires are subdivided into open and closed fires. *Open fires (Class IIa)* are characterised by the high speed of the flame front moving in the direction of partially opened windows, passages, and other room openings, which results in flame expansion to adjacent rooms and upper floors. In open fires, the speed of the combustion of flammable substances depends on physical and chemical properties, location in the room, and the existing conditions for exchange of mass gaseous fraction between the affected room and surrounding environment. Open fires are usually divided into two subgroups. The first includes fires in rooms with ceilings up to 6 metres high (such as in residential buildings, schools, hospitals, or administrative buildings), with fresh air inflow and the removal of gaseous combustion products at the same level. The second subgroup includes fires emerging in spaces with a ceiling height above 6 metres (e.g. sport halls, storages, industrial buildings, etc.), with openings for fresh air supply and the exhaust of gaseous combustion products at different levels. In case of fire, there is a fall of pressure in the height, and consequently, an intensive exchange of gaseous fractions mass between the affected space and the surrounding environment, as well as the high burning rate of present mass fire load.

Closed fires (Class IIb) occur in rooms/spaces with fully closed openings. A particular danger in these fires is the presence of substances that contain a large percentage of oxygen, or the presence of materials with highly flammable substances. The combustion of these substances and materials takes place at a high speed, even in the complete absence of an oxidiser.

3.2 Outdoor Fires

Outdoor fires are understood as the processes of uncontrolled combustion developed in open space, i.e. outside the building. Nonetheless, an outdoor fire may also occur at the external part of a building enclosure or at other external building parts, due to spreading from an indoor space, spreading from the exterior environment towards the building, or the conditions at the very location of such exterior building parts. Outdoor fires may be divided, conditionally, into:

- *Fires with progressive enlargement (Class Ia)*, also known as expanding fires. These fires expand at a variable speed and in different directions, depending on the conditions at the initial fire spot, the size of formed flame, the exchange of heat, and the mass of gaseous fractions, the speed, and direction of wind, etc. The size and direction of the fire front primarily depend on the distribution of mass fire load and the environmental parameters (wind and other weather characteristics);

- *Fires with nearly constant size after the termination of development stage (Class Ib)* are also known as non-expanding or spatially limited fires. In the development stage, however, Class Ib fires can spread to surrounding buildings, or develop into expanding fires;

- *Massive fires (Class Ic)* mostly occur in forests, in large warehouses housing solid and liquid combustible substances, or in blocks with buildings at high fire risk.

4 Fire Dynamics and Basic Parameters

Fire parameters are determined based on their influence on the environment (Jovanović & Tomanović, 2002), and are considered in the context of time. While studying fire parameters, their interdependence and connection with environmental (such as meteorological) parameters, fire load parameters, conditions for the exchange of mass gaseous fractions, and the spread of fires at the site should not be neglected.

Fig. 4.1 presents fire development phases with the dynamics of basic fire parameters (Jovanović & Tomanović, 2002). The upper diagram shows the dynamics of combustion of mass fire load through all three fire development phases, where Curve 1 represents the loss of the mass fire load, and Curve 2 indicates the speed of mass fire load loss. The middle diagram shows a change in the height of the flame (Curve 3), the concentration of oxygen in the room affected by the fire (Curve 5), and the concentration of combustion products (carbon monoxide and carbon dioxide) in the room affected by fire (Curve 4). The lower part of the figure provides a graphic illustration of the temperature regime in the room affected by the fire (Curve 6), then the change of the heat flux of the flame (Curve 7), the exhaust of air that touches the combustion zone through the openings (Curve 8), and the position of the neutral plane (curve 9), all on a timescale (Jovanović & Tomanović, 2002).

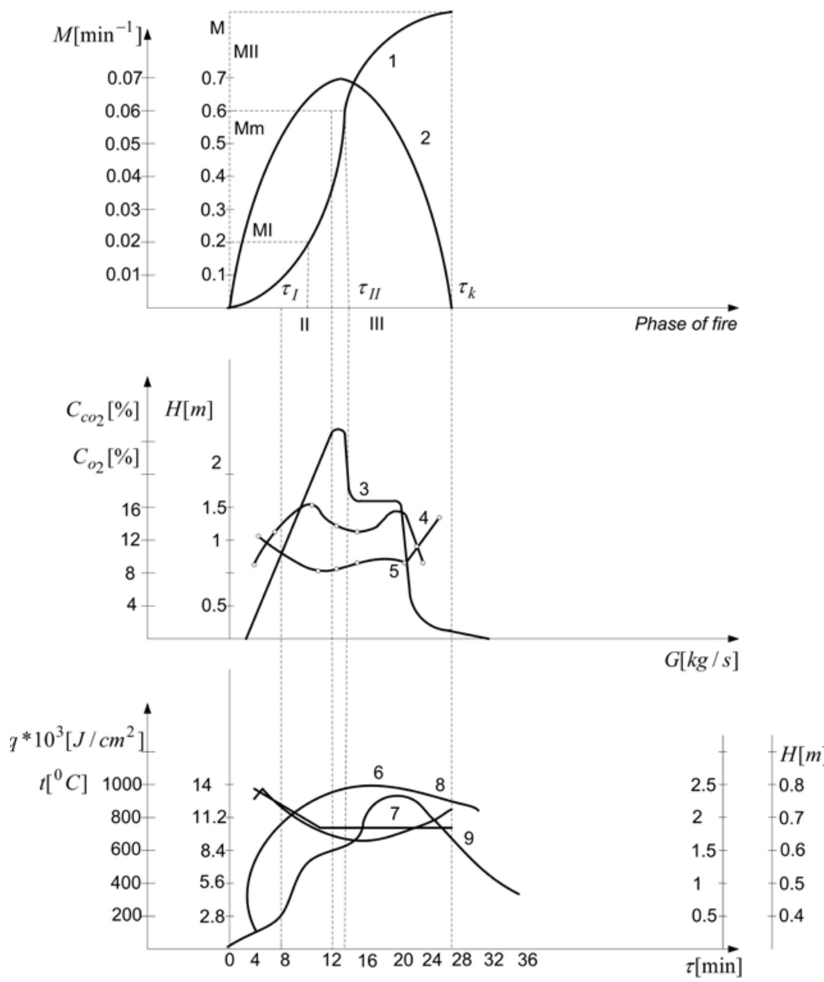

FIG. 4.1 Phases of fire development with the dynamics of basic fire parameters *(Jovanović & Tomanović, 2002)*

First phase

In the first phase of fire development, which is characterised by the continuous expansion of the initial hotspot over 80% of the mass fire load, the increase in the average room temperature, up to 200°C, is accompanied by increased air expenditure. After that, the expenditure of air slowly decreases. At the same time, the level of the neutral plane decreases in the opening region, resulting in a reduction of the surface area of the opening through which it touches the fresh air, i.e., increasing the surface area of the opening through which the formed mixture of combustion products and air leave the room. Due to the reduction of the surface for influx of fresh air, the volume of oxygen that touches the combustion zone reduces (up to 8%) with an increase in the volume of carbon dioxide in the mixture of combustion products and air leaving the room (up to 13%).

This is explained by the fact that, in temperature range of 150-200°C, there are turbulent exothermic decomposition reactions of the flammable substances, which are accompanied by a combustion increase rate under the influence of fire released heat. The amount of heat released in this time unit depends on the lower thermal power of the combustible material, from the combustion surface, the mass speed of material combustion per surface unit, and the incomplete combustion coefficient. In case of fire in an enclosed space, the heating of the present flammable materials and building structure is caused by heat exchange through conduction, convection, and radiation. Regardless of the mode of heat exchange, the time interval of the first fire phase entirely depends on the burning speed of the present mass fire load and the spread of the flame. Depending on the exchange conditions of gaseous fire mass and the surrounding environment, as well as of the composition and arrangement of mass fire load in an enclosed space, the duration of the first phase of the fire varies within the limits of 2-30% of its total length. At the end of the first phase, the temperature in the combustion zone increases rapidly, the flame height increases and catches most of the flammable materials and structures, and the concentration of oxygen decreases with the increase in the concentration of carbon dioxide, carbon monoxide, and other combustion products. These processes are directly dependent on the speed of combustion of a mass fire load affected by fire.

Second phase

In the second phase of the fire development, after reaching the maximum burning rate of the present mass fire load, the process is characterised by the constant presence of the flame and the constant speed of mass loss. During this period, all the aforementioned fire parameters reach extreme values. The maximum values are reached for the average room temperature, the concentrations of products of complete and incomplete combustion in the room, and mixtures of combustion products with the air leaving the room, the height of the flame that penetrates through the holes, its thermal radiation, and the air flow speed in the combustion zone. At the same time, the position of the neutral plane, and thus the fresh air inflow through the lower parts of the hole in the formation zone of the combustible mixture, as well as the oxygen content in the room, fall to a minimum. In this phase, all flammable and highly inflammable materials and materials are ignited, and the combustion of the combustible mixture takes place in the flame outside the room.

With the rise of temperature, the limit resistance of certain structures to the effect of fire is achieved. This is followed by their overheating, crack formation, and collapse. Due to the heat radiation of the flame, the risk of spreading the fire to neighbouring, fire-intact buildings increases.

Third phase

The third phase of the fire development is characterised by a rapid decline in the burning speed of still burning materials and components of the building structure, and their appearance in the form of smouldering. The temperature of the surrounding environment remains high for a long time. During the cooling period, some parts of the building may collapse. The thermal decomposition of the flammable materials can occur without any visible manifestations of the burning process (pyrolysis), smouldering, or combustion with occurrence of flame.

For instance, in a room with openings for the exchange of mass gaseous fractions, two processes can simultaneously occur: combustion of flammable substances near the openings with the appearance of flames, and pyrolysis in the interior of the room, which is conditioned by a reduced concentration of oxygen due to limited air inflow. In a room area near the opening, after thermal decomposition and gasification, flammable materials ignite simultaneously over the entire combustion surface at a high speed. If a fire hotspot is inside the room, two processes unfold simultaneously: the flame front goes in the direction of the opening and the combustion of fire affected materials behind the flame front. With an open fire present in the room, the speed of mass loss, the time of reaching the maximum combustion speed, and the total duration do not depend on the initial ignition co-ordinates. These parameters depend on the exchange conditions of gaseous fractions mass in the room affected by fire and surrounding environments, and from the physical and chemical characteristics of mass fire load.

5 Fire Protection Measures

The term *fire protection measures* refers to the determination of methods and procedures for preventing or eliminating the risk of fire on human lives, material goods, and the environment, while *safe conditions* are determined by the norms contained in the legal or technical regulations.

Preventive measures in achieving fire protection aim to prevent the outbreak of fire and reduce its consequences on people and material assets. One of the most important fire preventive activities is the implementation of fire protection measures at all spatial levels, from a region to a building. Fire protection measures aim to eliminate the causes of fire outbreak, prevent the occurrence and spreading of the fire, and ensure adequate means of fire extinguishing.

The majority of fires in urban areas occur in buildings. When the fire breaks out, the safety of people depends on their preparedness and the successful performance of the evacuation routes. In the past, evacuation was given the greatest importance; it was considered that if the routes are safe from smouldering and fire spreading, then timely and successful evacuation is possible (Kawagoe, 1958). Since the middle of the last century, the standards based on laboratory research have gradually developed. To date, unquestionable progress has been made, but the process has not yet been completed.

The development of fire protection standards, regulations, and practice is based on state interest and the interest of assurance companies

(Vidaković, M. & Vidaković, B., 2008). The state has a clear interest to protect people, material goods, and private capital, and for that purpose uses the following instruments: penal policy for non-compliance with international and domestic standards and regulations, e.g. CEN, ISO, IEC, SRPS (JUS); education programmes and actions; technological and technical protection measures based on laboratory tests; fire extinguishing measures carried out by fire-fighting and rescue units; legal inspections of the causes of occurred fires; judicial function; and national-level statistics envisaged to collect data on previous fires and accidents, so as to gain knowledge and prevent the occurrence of similar events in future.

The interest of insurance companies is aimed at preserving and increasing capital, based on better prevention and safeguarding of funds, through: standards; associations; statistics; tariffing; system of insurance conditions; risk management; preventive actions and preventive funds; education funding; elaboration of the nature of risk and possibilities of the maximum damage; determination of the fire cause; statistical data bases formation; development of new recommendations for legal regulations through laboratory tests; etc.. Fire-fighting activities are also performed by insurance companies that cover fire damages.

Fire protection represents a basic requirement as defined by the European Directive on Construction Products (CPD) (Council Directive 89/106/EEC), while more detailed conditions are prescribed by the legislation of individual member states and adapted regulations of candidate members, e.g. the Republic of Serbia ("Sl. glasnik RS", 132/2014 and 20/15). In 2011, the Directive 89/106/EEC (1988) on the harmonisation of laws, regulations, and administrative provisions of the member states relating to construction products was replaced by Regulation (EU) No 305/11.

International organisations such as the CEA (The European Insurance and Reinsurance Federation) and the CFPA-Europe (The Confederation of Fire Protection Associations Europe, of which Serbian non-governmental organisation DITUR is the full member) deal with the system of quality and reliability of fire protection systems, as well as the philosophy of fire fighting. As the world, and especially Europe, becomes more connected and intertwined (Božović, Živković, & Mihajlović, 2017), all contemporary threats need to be addressed multilaterally, just as in the case of functioning of the mentioned organisations.

5.1 Fire Protection in the Republic of Serbia

The Fire Protection Law of the Republic of Serbia ("Sl. glasnik RS", 111/2009, 132/2014, 20/2015) regulates and defines basic requirements for fire protection during planning and construction phases, and introduces *the main fire protection project* (Section 5.2) into the binding content of the building project documentation. Here, the obligations to estimate fire risks and calculate fire load are prescribed, which significantly influence the effectiveness of the fire safety of a building. The latest amendments to the 2015 law stipulate that the control over the application of preventive fire protection measures should be done in design, construction, and exploitation stages of buildings.

In addition to the Fire Protection Law, fire safety on a national level is further controlled by other regulations that address tall buildings, specific building types, infrastructure such as access roads, etc., as well as by the non-binding technical recommendations. There are also a number of technical regulations referring to electrical and gas installations, hydrant networks, fire detection and alarm systems, fire extinguishing equipment, smoke and heat extraction installations and systems, explosive gas and steam detection systems, and others.

Fire protection measures begin with the development of an investment program for construction, i.e. with the analysis of conditions for the construction of a building of a specific purpose. The National Law on Planning and Construction ("Sl. glasnik RS", 132/2014) prescribes that the investment program must be made on the basis of previous analyses and other experts' findings, inter alia regarding the conditions for fire protection. However, the method of analysing conditions and designing fire protection measures in the preparation of investment-technical documentation has not yet been defined.

5.1.1 Conceptualising the Fire Protection

The conceptualisation of fire protection precedes the development of the main fire protection project (Section 5.2). The conceptual fire protection of a building elaborates upon the optimal solution of complying with the fire requirements of the SRPS (JUS) and ISO standards, as well as insurance requirements for risk reduction, including insurance premiums.

The development of the conceptual fire protection project starts with the analyses of regulations tackling different spatial levels, the conditions at the location, and the purpose of the planned building: residential, educational, health care, cultural, entertainment, sport and recreation, trade, services, industry, etc. (Živković, 2011).

The Fire Protection Law requires that *spatial and urban plans*, as well as the decisions supplementing them with regard to fire protection measures, must provide: sources of water supply and the capacity of urban water supply network for fire extinguishing; distance between the zones envisaged for housing and public purposes from the zones envisaged for industrial facilities and special purposes; access roads and passages for fire-fighting vehicles; safety zones between buildings to prevent fire spreading, safety distance between buildings or their separation regarding fire; and the possibilities for evacuation and rescue.

Conditions for building construction on a specific cadastral parcel contained within the regulations are twofold, and relate to urban-technical and special requirements. Issued *urban-technical requirements* contain the data on urban and technical possibilities and construction restrictions. *Special requirements* include requirements and approvals from legally authorised bodies and organisations regarding municipal infrastructure and supply networks, protection of natural assets, immovable cultural properties, water management, traffic conditions, sanitation, fire and other conditions for protection against natural disasters, and the conditions for environmental damage prevention.

A fire protection concept for a building must address the above requirements and conditions to draw a solution that reduces the possible fire impact from the external environment on a proposed building, and vice versa, i.e. it eliminates the causative agents of fire, disables fire transfer (spreading) and enables easy, fast, and efficient localisation of a fire if it occurs. This means that the effective fire protection measures are those that are embedded in the urban and architectural concepts of a designed building. The optimal fire protection solution for a specific building reflects the optimal solution for fire protection at the urban level. Only when fire protection measures are integrated on different spatial levels will the protection be truly maximised. This fact gains additional importance in the context of climate change manifestations.

Furthermore, the effective fire protection of a building has to comply with the preconditions prescribed by the Fire Protection Law of the Republic of Serbia (fully adopted from the Annex I of the European CPD Directive 89/106/EEC) as the basic requirements to be fulfilled during the construction phase, regarding:

- maintenance of the load capacity of a building structure for a certain period of time;
- prevention of the spread of fire and smoke within the building;
- prevention of the spread of fire to neighbouring structures;
- enabling secure and safe evacuation of people.

To fulfil all of above-motioned requirements, besides complying with the regulations, standards, and other legal acts in the field of fire protection, it is necessary to conduct a fire risk assessment as the input for the definition of fire protection measures for structures, materials, installations, and protective systems and devices.

According to Milutinović and Mančić (1997), fire protection measures can be divided into:

- *Active measures*, including installation of alarm systems for fire detecting and reporting; incorporation of the smoke control and removal systems; installation of systems and devices for automatic fire extinguishing; providing mobile equipment for initial fire extinguishing; control of flammable substances; providing access to fire-fighting intervention; and fire protection management system; and

- *Passive measures*: division of a building space into fire sectors; evacuation planning; providing fire resistance to building elements and structures; and control of the flammability of elements and structures.

5.2 Main Fire Protection Project

The main fire protection project contains:

- *General conditions of fire protection;*
- *Fire risk analysis,* including designed characteristics of the building (purpose, layout, macro location, micro location, architectural characteristics, structural characteristics, applied materials); fire load; categorisation of the building according to the specific fire load; categorisation according to the type of technological process; possible fire class in the building; fire risk in the building (minimum required time of fire resistance, risk of explosion);
- Urban, architectural and structural *fire protection measures*;
- *Fire extinguishing system*: hydrant fire extinguishing network (external hydrant network, inner hydrant network); stable fire extinguishing system (sprinkler installations); mobile fire extinguishing equipment;
- *Electrical installations* - general and fire detection and alarm systems;
- *Lightning installation;*
- *Forced evacuation from the building;* and
- *Organisational measures for fire protection.*

According to the Fire Protection Law ("Sl. glasnik RS", 111/2009 and 20/2015), all listed segments should be organised into the following parts of the main fire protection project documentation: technical report; calculations; graphical documentation; and the bill of quantities.

Technical report contains: information about the location of a building; building description; fire risk assessment; division of a building into fire sectors; definition of evacuation routes; selection of construction materials on the basis of fire resistance; selection of interior materials with special requirements in terms of fire resistance; assessment of the risk of fire from technological processes and used or stored materials; description of the installations for automatic fire detection and alarming, detection of explosive and flammable gases, as well as the description of stable and mobile installations and fire extinguishers; defined evacuation routes for people and assets; selection of mobile fire-fighting equipment; and others.

Calculations basis of the main fire protection project presents the values for fire load for different fire sectors within one building, capacity of evacuation routes, time required for evacuation, etc.

Graphical documentation of the fire protection project comprises: a situational plan marked with neighbouring buildings and roads; plans of all floors and the roof; characteristic longitudinal and transversal sections with marked fire sectors; disposition of processing technological equipment and equipment belonging to fire extinguishing installations; and schemes of the systems for fire detection and alarming, gas detection, lightning protection installations, automated fire extinguishing systems, smoke and heat exhaust systems, ventilation systems, etc.

Finally, the main fire protection project contains *the bill of quantities* for the equipment and fire protection devices.

5.2.1 Fire Risk Calculation

Fire risk for a building is calculated according to the relevant technical regulations and standards in order to determine the need for the installation of stable systems for fire extinguishing when the obligation of installation is not defined by a special regulation. It depends on the possible intensity and duration of the fire, as well as the constructive characteristics of the bearing elements of the building (the resistance of the construction to the influence of high temperatures), and is calculated on the basis of the following formula (Erić, 2003):

$$Ro = \frac{[(Po * C) + Pk] * B * L * \check{S}}{W * Ri}$$

Here, *Ro* represents fire risk for the building; *Po* is the coefficient of fire load of building contents; *C* – coefficient of combustible contents in the building; *Pk* –fire load coefficient of the material embedded in building structure; *B* – coefficient of size and position of the fire sector; *L* – coefficient of extinguishing start delay; *Š* – coefficient of the fire sector width; *W* – coefficient of fire resistance of the load-bearing structure of the building; and *Ri* – coefficient of risk reduction.

The *fire risk of the building contents* (hazards for people, equipment, stored goods, etc.) (*Rs*) is calculated as:

$$Rs = H * D * F$$

Here, *H* represents the coefficient of hazard for people; *D* – property risk coefficient; and *F* - coefficient of smoke effect.

5.2.2 Fire Risk Assessment

When classifying buildings into fire hazard categories, the following elements are considered: fire risk of the building; significance and size of the building; convenience of the building location; and vicinity of the local fire department. The fire threat to the building, that is, the fire risk, is the basis for the fire protection design.

The assessment of fire risk can be done by using the following factors:

- fire load, which depends on the type of building and, in this respect, the quantities and calorific value of combustible material;
- combustibility of raw materials and materials used in the building, determined by the possibility of ignition and combustion speed, where the combustion rate represents a very important factor, as it also affects the speed of fire spreading;
- properties of combustible material on which the formation of smoke and gases depends, and on the basis of which it is possible to know if smoke is formed as a result of combustion, as well as congestion and corrosive gases;
- layout of rooms, number of floors, and communication routes, and in connection with this, the division of the building into the fire sector, which directly impacts the spreading and transmission of the fire;
- possibility of destruction that depends on the sensitivity of installed materials, machines, and devices;
- concentration of values that depends on the value of materials, installed machines, devices, etc.;
- danger to people possibly affected by smoke, gases, and fire heat, with the emphasis on the concentration of people; and
- intervention time, consisting of three important time periods: time until fire detection, time until fire fighters' arrival, and the time required for fire extinguishing.

To reduce the vulnerability of a building against fire, it is necessary to anticipate appropriate fire protection measures: designing and installation of external and internal hydrant networks; distribution of mobile equipment and fire extinguishers; designing an automatic fire alarm system; planning of the appropriate number of evacuation doors; ensuring that all evacuation routes are always free; and designing the electrical installation according to the conditions of exploitation of the building.

5.2.3 Evacuation Calculation

In the event of a fire in a building, panic followed by very serious consequences may occur. Therefore, general preventive measures may also be considered as those concerning the rapid abandonment of the affected space. Here, building location is of particular importance, followed by access points, corridors, exits, or communications, all of which must ensure both safe movement and safe evacuation.

Evacuation is the removal of persons at risk from a dangerous place to a safe place. It is calculated for all persons who occupy the building. The basic parameter that determines the effective evacuation is the time in which it can be successfully performed. In the absence of appropriate domestic regulations with mandatory application, SPRS (JUS) TP 21 is used for the calculation of evacuation time (Mijović, 2002).

6 Discussion and Conclusions

Fire protection should be organised in accordance with the latest scientific knowledge and the engagement of all responsible and interested stakeholders. This is a basic precondition for the successful protection of human life, material goods, and the environment (Hasofer, Beck, & Bennetts, 2007). Fire protection challenges can be answered by implementing appropriate activities and procedures, as well as taking preventive fire protection measures, which would lead to an increase in fire safety. Given the possible consequences on people and material goods, problems related to fire protection certainly represent the most serious problems when it comes to the safety of buildings. Fire safety implies the implementation of preventive fire protection measures aimed at preventing the occurrence of fire in a building. Unlike the preventive measures, the choice of adequate repressive protection is conditioned by a proper assessment of a possible class of fire and the basic parameters of its development within certain development phases, i.e. its dynamics in time and space, which is in addition to the geometry of the space, the mass fire load, the linear fire development rate, etc., conditioned to a large extent by the influence of the corresponding parameters of the external environment. If a fire occurs in a building, it is necessary to prevent its rapid spread, effectively evacuate people, and prevent the transfer of fire to the surrounding areas.

Effective preventive protection first requires a high degree of knowledge of the uncontrolled combustion process, as well as of the fire development process. The resistance of structural elements of a building is very important for the overall assessment of its integrity. The building should be constructed from such structural elements that, in case of fire, will be stable for a certain period of time. To properly assess the fire risk, identified dangers leading to the fire and the undertaken preventive measures should be addressed through a systemic approach and by understanding its complexity. The fire risk assessment is a complex process requiring the setting up of a multidisciplinary team of experts in the fields of electrical engineering, mechanical and civil engineering, architecture, technology, fire protection, and other relevant occupations (Woodrow, Bisby, & Torero, 2013).

In the Republic of Serbia, the harmonisation with the EU regulations and standards is still on-going. Performing inspection and supervision of the implementation of legal solutions, and raising awareness and culture on the fire safety of all citizens, will create a safer living and working environment for all. The measures aimed at protecting people and property from fire will yield results only in the case of the coordinated and combined activity of all responsible stakeholders in society.

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