PREGLEDNI RAD - Scientific review

Tactical aspects of extinguishing fire in closed spaces

Taktički aspekti gašenja požara u zatvorenom prostoru

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SUMMARY

Fire, as a process of uncontrolled burning, is always accompanied by a threat to human life and property. Often, this threat results in human victims. The spread of fire can vary depending on the factors and conditions in place. The location of a fire is a very important factor, and one of the most common locations of fire spreading a closed space. Most fires occur in closed spaces, particularly residential, industrial or commercial buildings. Fire can spread across virtually the entire closed space in these structures, from basements to attics. Residential buildings are among the most interesting structures in this sense, given the large number of people inside. Fire extinguishing tactics in residential buildings can vary depending on different factors, such as the function of the building in question, its interior arrangement, arrangement of communication routes, construction materials, etc. Therefore, it is very important to apply the proper tactic for fire extinguishing in closed spaces using proper fire extinguishers. This paper presents examples of extinguishing fires in closed space with proper tactics the potential use of simulation software as an important tool.

Key words: fire, extinguishing, closed space, tactics, simulation.

Sažetak

Požar kao proces nekontroliranog sagorijevanja uvijek je praćen ugrožavanjem ljudskog života *i štetom na materijalnim dobrima. Često je rezultat ugroze praćen ljudskim žrtama. Širenje požara može biti različito u ovisnosti od različitih faktora. Lokacija požara predstavlja veoma važan faktor. Jedna od veoma mogućih lokacija širenja požara je zatvoreni prostor. Najveći broj požara događa se u zatvorenom prostoru-stambenim objektima, industrijskim objektima, poslovnim objektima itd. Požar može zahvatiti svaki zatvoreni prostor ovih objekata, od podrumskog prostora pa do tavanskog prostora. Naravno, jedni od najinteresantnijih objekata u ovom smislu su stambene zgrade, najviše zbog velikog broja ljudi unutar njih. Taktika gašenja požara u ovom slučaju može biti različita u zavisnosti od različitih faktora, kao što su namijena zgrade, unutrašnji raspored u zgradi, raspored komunikacijskih ruta, materijala od kojih je zgrada napravljena itd. Dakle, veoma je važno izabrati odgovarajuću taktiku za gašenje požara u zatvorenom prostoru i odgovarajuća sredstva za gašenje.*

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Ovaj rad je napisan kako bi pokazao primjere gašenje požara u zatvorenom prostoru i moguću upotrebu simulacijskog softvera kao pomoćnog alata.

***Ključne riječi**: požar, gašenje, zatvoren prostor, taktika, simulacija*

INTRODUCTION

Uvod

The uncontrolled spread of fire demands a number of specific activities to effectively extinguish it. These activities can be summarised and presented as fire extinguishing tactics. Fire extinguishing tactics include a range of tasks, from operational tasks; protecting people and property; tasks in providing assistance in other non-fire situations, such as airflow, earthquake, terrorist attack, traffic accidents and other accidents; proper management of fire brigades during extinguishing; the use of fire extinguishers, and more. Fire extinguishing tactics are a very important part of fire extinguishing and demand broad coordination of different sciences and disciplines (Blagojević 2015; Glavinić and Rašković 2016).

The development of a fire can be described through four different phases. Initially, the focus of the fire is small and fire products are mostly invisible. This represents the primary phase. With the appearance of smoke, the second or smoldering phase begins. With flaring, this develops into the third, or burning phase. The burning phase is characterized the rapid development (spread) of the fire. After this phase, the fourth or heat development phase occurs. Fires can be classified in several ways, depending on the factors and criteria used. Depending on their location, fires can be divided into two categories: outdoor fires and fires in confined spaces. Related to the scope of the fire, they can be divided into small fires, medium fires, large fires and block fires. Other classifications also exist (Blagojević 2015, 2018; Jevtić 2015).

The majority of fires occur in closed spaces, especially in buildings, industrial structures, commercial buildings, storage facilities, and similar closed structures. These fires demand special tactics of extinguishing, depending on a number of factors: type and function of the building, interior arrangement of spaces and objects, arrangement of communication routes, construction materials (in the sense of their fire resistance), etc. Construction materials are particularly important in fire extinguishing. Buildings can be divided into fireproof, semi fireproof and non-fireproof buildings based on the flammability level of the materials used to construct parts and elements of the building. Non-fireproof buildings and objects are certainly the most significant problem for fire extinguishing and fire brigades. These buildings and objects were built from parts and elements that are not fireproof, and therefore are easily ignited, deformed and destroyed. Fires in such buildings and objects tend to spread quickly throughout the building or object, even

in the initial fire phase. These fires demand special extinguishing tactics, requiring the fast action of fire brigades, rapid use and a wide-scale concentration of fire extinguishers, and quick and safe evacuation. Fires in these structures can occur in the basement, ground or other floors, attic, mezzanine structures, wall constructions, floor structures, etc. An important problem faced by fire brigades in the case of extinguishing fires in confined spaces is the limitation of space combined with other limitations - in speed, reactions, number of firefighters and fire extinguishers, etc.

Examples of a simulation of fire in a closed space, where objects are constructed of different fireproof materials are shown in Figures 1, 2 and 3 (Glavinić and Rašković 2016; Jevtić 2014, 2016, 2017).

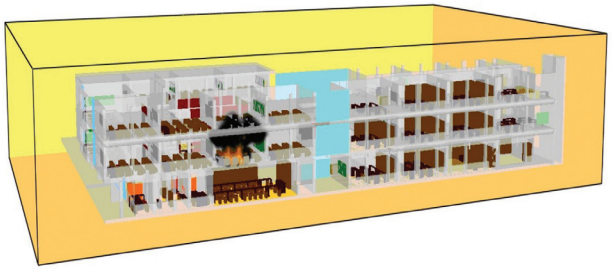


Figure 1. The simulation of fire and smoke spreading in a closed space: the case of the first floor of the Nikola Tesla Electrotechnical Secondary School in Niš

Slika 1. Simulacija širenja požara i dima u zatvorenom prostoru - slučaj prvog kata Elektrotehničke škole „Nikola Tesla" u Nišu

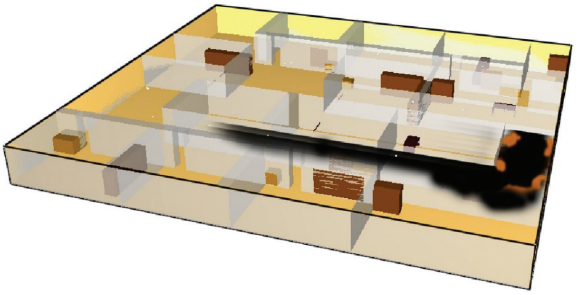


Figure 2. The simulation of fire and smoke spreading in a closed space - the case of a storage area

Slika 2. Simulacija širenja požara i dima u zatvorenom prostoru - slučaj skladišta

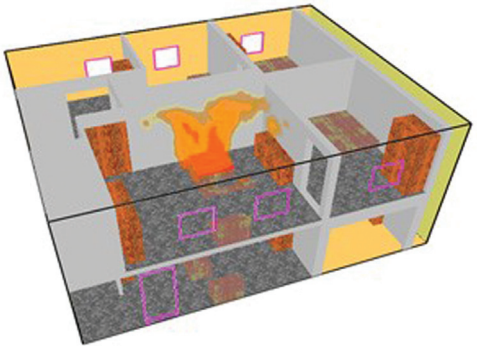


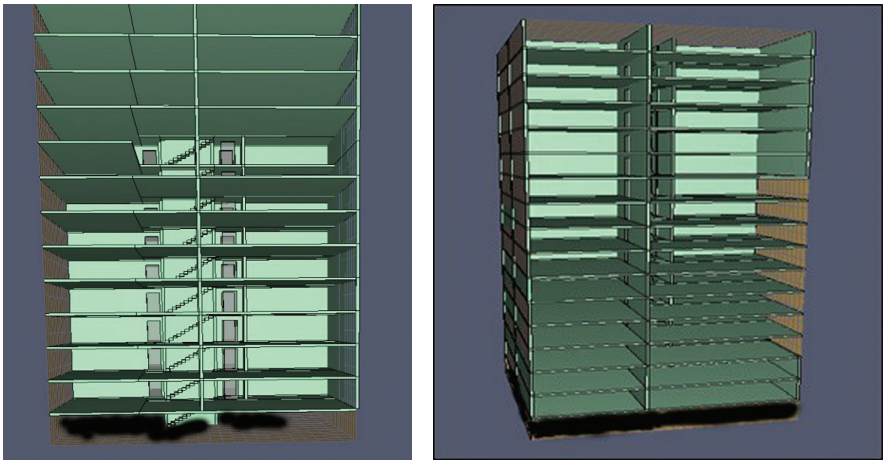
Figure 3. Simulation of a fire in a closed space in residential conditions - fire development in the bedroom

Slika 3. Simulacija požara u zatvorenom prostoru u kućnim uvjetima - razvoj požara u spavaćoj sobi

FIRE EXTINGUISHING IN BASEMENTS - Gašenje požara u podrumskim prostorima

Most residential structures are built with basement spaces under the main floor. A smaller number of buildings have basements on top of the building - these are mostly buildings intended for military personnel. Fires in such spaces are a highly complicated and dangerous task in the sense of fire extinguishing and firefighter protection. Basement positions are such that they enable the accumulation of smoke and fire products and their spread through communication routes. Due to a lack of fresh air, at the initial stage of fire, while oxygen is still present, complete combustion occurs. Over time, complete combustion proceeds into incomplete combustion, which significantly increases the temperature and leads to the development of gases, fumes and smoke. In the case the basement has openings, fire penetrates quickly to the ground floor. In most cases, basement structures are resistant to fire for a duration from 2 to 4 hours without deforming or collapsing. In most cases, the entrance to basement spaces leads through a central staircase, rarely from other sides (when there is a separate entrance to the basement).

From the tactical aspect, the observation group must be the first to start fire extinguishing. This group is required to locate the fire and obtain other important information, such as the type of building material, direction of fire spread, etc. with all precaution measurements (adequate personal protection, air supply equipment, light equipment, etc.). The most important task is to precisely determine the focus of the fire, which in some situ-



a) b)

Figure 4. Simulation of smoke spreading in the basement of a residential building for slow (a) and fast (b) fire

Slika 4. Simulacija širenja dima u podrumu stambene zgrade za spori (a) i brzi požar (b).

ations is nearly impossible due to the presence of flames, smoke and other obstacles. In such situations, the only potential way is fire extinguishing from the other side, through openings. From the safety aspect, this is the best approach in such situations, though from the fire extinguisher consumption aspect, this approach implies unnecessary and unreasonable consumption of fire extinguishers because of inaccessibility, an inability to direct fire extinguishers towards the focus of the fire, more difficult observation of fire focus, etc. The main limitation in such situations is the lack of space and the dimensions of available openings. In cases where it is not possible to localise and eliminate the fire, the only option remaining is to break through the ceiling of the basement directly above the fire focus, while protecting the ground floor with several water jets. If possible, all highly flammable materials should be removed. Once the fire is extinguished, the fire focus should be cleared and the used fire extinguishers removed, and in such cases large quantities of water must usually be pumped out. Simulations of fire in the basement of a building with two different fires (slow and fast) are presented in Figures 4a and 4b. The value of the fire growth coefficient (parameter a [kW/s^2]) for the slow fire in the simulations was 0.00293, while the value for the fast fire was 0.0469 (Glavinić and Rašković 2016; Jevtić, 2020c).

FIRE EXTINGUISHING ON GROUND AND OTHER FLOORS - Gašenje požara u prizemlju i na ostalim katovima

Fire extinguishing in tall residential, industrial, commercial or other buildings is a difficult, complex and open task. This task always calls for a large number of firefighters and fire extinguishers, very often with great risk for the occupants inside and the firefighters themselves. In the first step, access to the building must be cleared for firefighters, which is frequently hindered by parked cars. As such, the number of fire vehicles that can be used is limited, and this is one of the most important limitations in such cases. This is especially important for buildings with multiple floors requiring the use of vehicles with hydraulic platforms and aerial ladders. The speed of fire observation depends on different factors, such as the number of staircases, emergency staircases, elevators, etc.

Generally, elevators should not be used because of potential malfunctions and power supply failure. Further, elevators are quickly filled with toxic and explosive combustion products. One of the most common, toxic and dangerous combustion products is carbon monoxide, as the product of incomplete combustion. Its toxicity is so great that this gas reacts three hundred times faster with hemoglobin than oxygen, often resulting in a fatal outcome as occupants suffocate without even realizing it. Furthermore, this gas is also highly explosive, with an explosive field ranging from 12.5 to 74.2% in volume. Only acetylene

and hydrogen have greater explosive ranges than carbon monoxide. Explosions that occur in other parts of the building can direct generated energy directly into the elevator shaft, and for any firefighters or occupants in the elevator at that moment, the outcome can be tragic and fatal.

Fire in the building can also occur on the ground floor or a higher floor. Smaller fires in buildings can be successfully extinguished if buildings have a well-designed and functional hydrant network, which can be wet or dry, depending on the presence of water in the pipes. Many buildings have hydrant pipes and jets on every floor in a special labeled metal cabinet, which significantly aid in localising the fire to improve firefighter activities and accelerate complete fire extinguishing.

As stated, buildings are high-risk structures from the safety aspect. The higher the floor where the fire occurs, the higher the risk, with a decrease in the possibilities for safe evacuation and successful extinguishing. Fires in buildings can vary depending on where the fire occurred and where it has spread: fires in one or more different areas, affected building construction, electrical or other installations, affected devices in the building, affected materials located inside the building, etc.

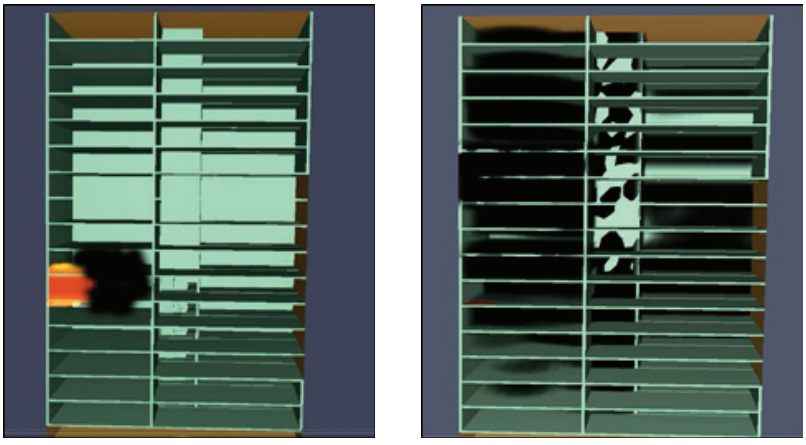
Depending on the materials inside the building, fire can achieve different temperatures. It can spread via horizontal and vertical surfaces (ventilation ducts and compartments, wiring and installation ducts channels and compartments, smoke ducts, etc.). Temperatures over 1000°C are very hazardous for the construction elements of the building. In most cases, fires spread towards the top of the building, though in some cases towards the lower levels of the building.

A fire on the ground floor does not generally represent a high-risk fire, in terms of its complexity and hazard for occupants and firefighters. However, the possibility exists, depending on the type and quantity of combustible materials located on the ground floor, that fire will spread to the surrounding rooms and upper floors. For that reason, this type of fire must be treated with enough fire jets, directly to the focus of the fire and above and below the focus of the fire. Also, protection sectors must be organised at adequate locations. The type of fire extinguisher will depend on the characteristics of combustible materials, but in most cases, the main fire extinguisher will be water in the form of fog and sprayed water. In such cases, the use of hydrants can often significantly limit the spread of fire, as early as in the observation phase before the fire track is formed. In the case of the ground floor, observation is a crucial phase for successful extinguishing. Jet numbers should be adequate in relation to the speed of fire spread and its volume. By observation, the location and dimension of spaces occupied by the fire and the type of combustible material must be identified. Also, directions of fire spreading, construction material characteristics, and material properties must be determined. In most ground

floor fires, evacuation of occupants is not an issue. Evacuation should be performed via stairs or windows as required. If panic prevails among the occupants, mobile fire equipment for evacuation should also be used.

It is desirable to send one team of firefighters equipped with air apparatus, to open windows on the stairs and to eliminate panic among the occupants. The main aim is extinguishing the fire focus from several directions and with several jets, while also protecting the area above and below the fire focus. In case of heavy smoke, smoke protection should be carried out by opening doors by vertical and installation of ventilation equipment near the entrance. After extinguishing, it is very important to thoroughly examine and check all rooms occupied by fire.

When it comes to fire extinguishing on other floors, especially higher ones, it is important to note that the number and size of engaged teams, extinguishers, vehicles, and equipment, as well as the complexity and danger level will depend on the height of the floor where the fire started. In the case of higher floors, several specially equipped teams must be engaged for reconnaissance purposes. Special equipment includes air apparatus, ropes, lighting equipment, technical interventions equipment and communication equipment. Also, they should be equipped with a set number of C-hoses and jets for potential connection to the building's hydrant network. Once these teams have reached the floor where the fire occurred, they must determine the fire intensity, an area occupied by fire, damage caused, potential for fire spreading, location and number of fire sectors, potential for fire team activities, a threat to human life, evacuation potential, etc. Simulations of fire and fire spreading on higher floors and through a residential building are presented in Figures 5a and 5b.



a) *b)*

Figure 5. Simulation of fire (a) and smoke (b) spreading through the floors in a residential building

Slika 5. Simulacija širenja požara (a) i dima (b) kroz katove u stambenoj zgradi.

The evacuation of endangered occupants must be a priority. Panic, stress, and visual effects (flame dimension, smoke quantity and other fire consequences) could have a strong effect on occupants, and therefore it is imperative that evacuation be started as soon as possible. To do so requires the determination of evacuation routes and the number of required firefighters and extinguishers. Reconnaissance teams must consider and determine all evacuation needs. Evacuation can be performed via regular staircases, emergency stairs and elevators, or, if they are deemed unsafe, by the use of mobile fire techniques. The presence of immobile or hardly mobile occupants is a significant challenge.

The installation of fire tracks and their locations depends on the current conditions and fire behavior. The classic equipment is used: adding and dividing hose apparatus, B- and C-hoses with adequate jets, etc. In the case several fire sectors must be formed, communication between sectors must be continuous. Nearly every fire extinguishing action on higher floors calls for use of fire platforms and mechanical ladders. Beside evacuation, they are also intended for effective fire extinguishing with installed jets. The proper formation of evacuation and extinguishing sectors, as well as protection sectors, is very important, as protection sectors serve to eliminate the possibility of fire spreading. The conditions of fire on higher floors require that all fire extinguishing actions are performed using ventilation apparatus and adequate protection equipment, and sometimes with the use of asbestos fire suits. It is very important to evaluate the degree of fatigue of firefighters and to replace them as necessary. After the fire extinguishing action is completed, a detailed examination of all the areas where extinguishing was performed is then conducted (Glavinić and Rasković 2016; Jevtić 2018, 2019, 2020a, 2020b, 2021).

FIRE EXTINGUISHING IN ATTICS AND ON ROOVES - Gašenje požara na tavanima i krovovima

Fire extinguishing in attics and on rooves is a highly complex intervention, primarily due to the inaccessibility of these spaces. The functions of attics can vary: they can be used as residential areas, storage areas, an elevator stations, common rooms, cellars, etc. For that reason, materials of varying combustibility can be found in these areas. In addition to their combustion properties, these materials can significantly disable the approach and access to the fire focus. An interesting fact is that an attic fire can also lead to fire at a higher level, where there is the potential for stronger wind flow, which implies stronger combustion intensity. Generally, fires in attics and on rooves can be in the form of an open roof fire or closed roof fire.

An open roof fire is any kind of fire that has overtaken the outer side of the roof. The main characteristic of this type of fire is that it quickly spreads horizontally. A closed roof fire is any type of fire that has overtaken the construction elements of the roof

in an enclosed attic space. The main characteristic of this kind of fire is that it causes the construction to collapse after some time and develops into open fire.

The main tactical procedure for this type of fire is an inner approach. These fires are burning at a certain height, and accordingly cannot be extinguished from the ground level as the fire is usually out of the range of jets. Therefore, the location of the jet controller should be above the fire focus. A very important task is to keep water flowing down the roof to cool the roof construction and its elements. This water supply must be permanent and continuous, and this is the most crucial factor for effective, fast and undisturbed fire extinguishing. Once the main fire focus has been extinguished, one part of the roof construction should be opened to allow the remaining fire products to escape. Throughout the extinguishing action, there is the threat of abrasion, and accordingly, the movement of firefighters through the attic and on the roof must be very careful. All precautionary measures must be taken, particularly the use of ladders, platforms, mobile equipment, etc. Where there is an internal hydrant network, the fire extinguishing actions can be finished quickly. Once the fire has been extinguished, all areas that were on fire must be examined to check if there is any hidden fire focus left. During fire extinguishing, all areas below the roof must be secured in case some part or element of the construction collapses, and evacuation of the occupants is essential.

It is also important to note that fire in buildings can spread over inner parts such as pores and hollows. Fires in these parts of the buildings are difficult to pinpoint. They are characterised by longer-lasting, incomplete and low combustion. These fires can occupy large areas with a high potential of construction collapse. In such cases, great amounts of oxygen come into contact with fire, initiating massive ignition of fire with many flames and smoke (Glavinić and Rašković 2016; Jevtić and Blagojević 2018).

FIRE EXTINGUISHING IN CHIMNEYS AS A SPECIAL CASE OF FIRE EXTINGUISHING IN CLOSED SPACES - Gašenje požara u dimnjacima kao specijalni slučaj gašenja požara u zatvorenom prostoru

Chimneys are common structures in buildings and represent vertical channels whose function is to enable the channelling of smoke to higher areas and to also enable the inflow of oxygen for better combustion. Their dimensions are standardised, depending on the chimney height and fireplace. Chimneys are built from concrete, but they can also be constructed of steel pipes. The main principle of chimney function, i.e., to discharge gases into the atmosphere, is based on the difference in specific weight between hot gases in the chimney and the cold outer air, and the difference in pressure between the interior of the chimney and the outer atmospheric pressure.

Fires in chimneys are very frequent. The main problem in chimneys is soot, which settles on the chimney walls over time and can easily be ignited by spark or flame. It is even considered that firing the soot in chimneys is the best way to clean the chimney. A large number of house fires begin this way. Soot combusts very gradually, and so the fire inside the chimney channel rises. Generally, soot is pure unburned carbon that is able to reach temperatures over 1000°C during combustion. These temperatures can cause substantial heating of the chimney construction. As a consequence, different deformations and fractures can occur throughout the chimney.

Fire in chimneys easily passes onto construction elements and materials of a house or building. Also, flame and sparks from the chimney can easily land on the roof and other parts of a house or building, causing the transfer of fire to the neighbouring houses or buildings. Old and porous chimneys present a specific hazard. During combustion, toxic and poisonous combustion products can enter the structure and rooms and cause even fatal consequences.

The main task of firefighter brigades when extinguishing a chimney fire is to stop the fire from spreading to the immediate surroundings. Modern instruments, such as thermal cameras and other thermal devices, can quickly and easily locate the fire in the chimney. The use of water as a fire extinguisher in these situations is not an option because an explosion may occur as a consequence of thermal dissociation, while the rapid cooling of the chimney can cause it to crack. The most common method of fire extinguishing involves closing all openings with wet clouts. In case the extinguishing action must be finished quickly, dust can also be applied. Once the fire has been extinguished, all residual soot must be removed (Glavinić and Rašković 2016; Šipuš 2015).

CONCLUSION

Zaključak

Fire extinguishing in closed spaces is a difficult, complex and common task for fire brigades. In fact, most fires start in closed spaces and areas, such as houses, buildings, industrial or commercial structures, chimneys, etc. Many aggravating factors (limited interior space, height, inaccessibility, etc.) can cause a tragic outcome if the fire extinguishing actions are not properly prepared and executed. The first and primary task is to evacuate the occupants from the structure, which can be both difficult and dangerous for both occupants and firefighters. For these reasons, the tactical approach of firefighters must be at the highest level, well analysed and well prepared. Firefighters must undergo adequate physical and technical preparation with proper equipment. Although the limitations of this paper do not permit a description of all the cases and tactical procedures, its aim was to present fire extinguishing in closed spaces with adequate tactical actions and procedures.

In recent years, the use of simulation software has become widespread in fire protection and fire extinguishing. With proper simulation software, it is possible to predict fire and smoke spreading through a specific structure and based on those facts, to prepare the most effective use of firefighters, fire extinguishers, vehicles and tactics. A particular benefit of simulation software use is its potential to calculate and predict the most effective means for human evacuation. There are many different simulation software packages in use today, such as Pyrosim, Pathfinder and others.

Future research should be focused on using simulation software to adequately create potential scenarios that could occur during a fire. This scientific approach would give very important and valuable information for firefighters in the selection of tactic, fire extinguishers and means of evacuation, thereby increasing the safety of firefighters and decreasing the consumption of fire extinguishers.

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