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THE FIRE SIMULATION AS A SAFETY ADVANTAGE IN FIRE PREDICTION AND FIRE PROTECTION

Abstract: *Fire presents the process of uncontrolled combustion that makes material damage and endangers human lives. It is important to know many factors that fire depends on for successful design and realization of fire protection systems. One of the most effective, the most economic and the most reliable ways to determine propagation of potential fire is the use of simulation programmes. In this paper, the usage of the PyroSim 2012 simulator in the potential fire determination was presented. A simulated facility was chosen to be the Electrotechnical school „Nikola Tesla“ in Niš.*

Key words: fire, simulation, FDS, evacuation

INTRODUCTION

One of the most important tasks in designing buildings is prediction and projection of the adequate fire system. Related to many different factors, such as building's purpose, geographic location, law and other regulations, technical and human surrounding and similar, the fire elimination, its detection at the early stage (such as its localizing and stopping potential propagation) are the tasks of crucial importance, above all, for human lives and safety of material properties. But even with the respect of strict standards, rules and measurements, it may form the unpredictable situations in sense of the uncontrolled and unpredictable fire propagation. Large numbers of different parameters that control fire further complicate the realization and design of the fire protection systems.

One of the most important fire parameters is combustion. The combustion presents the series of chemical reactions between the fire material and oxygen, where the release of heat and smoke is present. To reach the combustion process, the presence of all components of the fire triangle is required: fire material, heat source and oxygen, which means that the lack of any of noted components stops the combustion process. If the combustion process comes without influence of the external source, it could be defined as a self-triggering process.

The combustion process consequence is the heat transfer. According to the fire detection, it is very important fact that the heat, as the measure of warming, presents the only parameter that could produce the signal which does not need to be amplified. There were three basic mechanisms of the heat transfer: conduction, convection and radiation.

An essential parameter that appears in the combustion process is smoke. The smoke presents the suspension of the liquid, solid and gas particles. According to the fire material and combustion conditions, every fire was followed by the release of some combustion products, which had a great appliance in the fire detection. Because of the reason that it develops at the fire early stage, the smoke is one of the most used fire sizes for fire detection.

The flame is also very important factor for fire detection. The flame implies gas environment where the physical chemical reactions of the reactants participator are happening. Regardless the classification, every flame is characterized by two important characteristics: the presence of the high temperature area (the combustion zone) and adequate gas current that the transfer of the mass and heat relief was realized. One of the good examples how fire could easily turn to the uncontrolled process is presented in figure 1.

Figure 1. *An example of the uncontrolled fire propagation (https://www.google.rs/search?q=slike)*

According to the above mentioned, it could be concluded that the fire is characterized by large number of parameters as the uncontrolled combustion process, whose properties and specifications could be used for successful detection and neutralization. Also it could be out of control and it could start to propagate unexpectedly.

One of the most successful and most frequently used ways for potential fire prediction in safe and economic way is the usage of the adequate simulation software. Its importance is huge according to the fire consequences that may occur as the results of the unpredictable fire propagation [1, 3].

SIMULATION MODEL

PyroSim is a graphical user interface for the Fire Dynamics Simulator (FDS). FDS models can predict smoke, temperature, carbon monoxide, and other substances during fires. The results of these simulations have been used to ensure the safety of buildings before construction, evaluate safety options of existing buildings, reconstruct fires for post-accident investigation, and assist in firefighter training. FDS is a powerful fire simulator which was developed at the National Institute of Standards and Technology (NIST). FDS simulates fire scenarios using computational fluid dynamics (CFD) optimized for low-speed, thermally-driven flow. This approach is very flexible and can be applied to fires ranging from stove-tops to oil storage tanks. It can also model situations that do not include a fire, such as ventilation in buildings. FDS and the Smokeview visualization program are both closely integrated into PyroSim. The PyroSim interface provides immediate input feedback and ensures the correct format for the FDS input file. It is possible to work in either metric or English units and to switch between the two at any time. In addition, PyroSim offers high-level 2D and 3D geometry creation features, such as diagonal walls, background images for sketching, object grouping, flexible display options, as well as copying and replication of obstructions. It is possible to import DXF files that include either 3D faces or 2D lines that can be extruded to create 3D objects in PyroSim [4].

In this paper, the potential fire propagation in the Electrotechnical school škole „Nikola Tesla“in Niš has been presented.

The simulation model of the school was projected according to its real dimensions. The Electrotechnical school “Nikola Tesla” in Niš is the secondary vocational school with more than 800 pupils and more than 100 employees. The school building itself is huge and it consists of a laboratory part, classrooms part with offices, toilets, a library and physical education hall. The approximate building’s ground surface is about 2542, 91 m^2. The building has three floors with maximal height about 12 m.

The laboratory part of the Electrotechnical school “Nikola Tesla” has also three floors. At the base floor of the laboratory part there are several laboratories, stuff office, a carpenter room, a canteen, pupils club and the room with refrigerating devices. There are onlz laboratories at the first and the second floor. The classrooms in Electrotechnical school “Nikola Tesla” are located in three floors. At the base floor, there are a library, teacher’s office, administrative offices (director, vice director, law service and finance service), waiting and parents receiving room. The first and the second floor of the classrooms part consist of eighteen classrooms, nine per every floor. Every floor has male and female toilets. The physical education hall is a separate building which connects to the school building at the first floor [5].

The Electrotechnical school „Nikola Tesla“in Niš and the part of its interior are presented in Figures 2 and 3, while the presentations of simulation model are presented in Figures 4 and 5 [6].

Figure 2. *Electro-technical school „Nikola Tesla“in Niš*

Figure 3. *The interior part of the Electro-technical school „Nikola Tesla“in Niš*

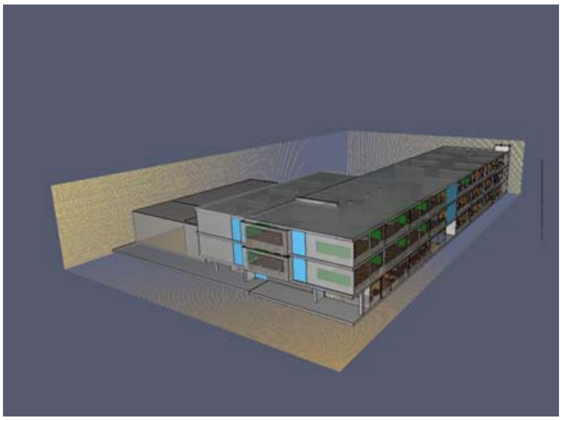

Figure 4. *The PyroSim 2012 simulation model of Electrotechnical school „Nikola Tesla“ (front view)*

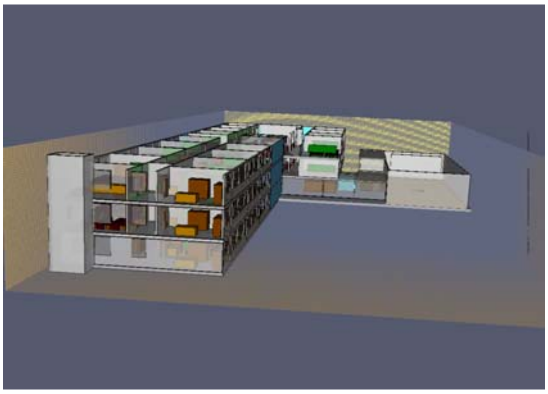

Figure 5. *The PyroSim 2012 simulation model of Electrotechnical school „Nikola Tesla“ (back view)*

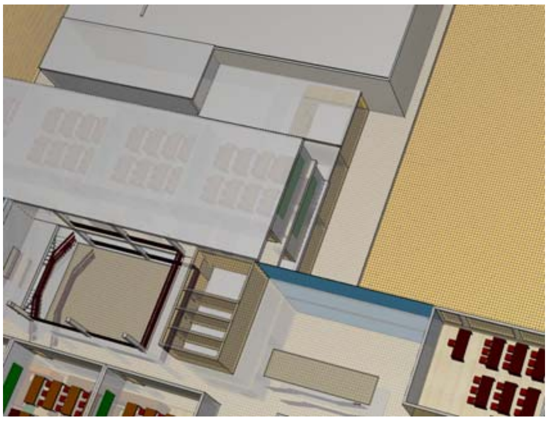

Figure 6. *The PyroSim 2012 simulation model of Electrotechnical school „Nikola Tesla“ (above view)*

At the interior of the simulation building, there were simulation models of doors, floors, desks, chairs, cupboards and lot of other inventory parts, so the simulation model was as much realistic as it was possible. Each of inventory parts has its own thermal properties that were defined by the program. The arrangement of these objects could significantly affect the fire generation, moving and propagation through the whole object [7, 9].

Table 1. *The list of objects and their dimensions used in simulation*

Number of objects	Object	Dimensions	Material
967	chair	0,4m x 0,4m x 0,4m (0,05 m thickness)	plywood
1	carpenter desk	3m x 1,5m x 0,75m (0,042 m thickness)	oak
76	middle desk	2m x 0,8m x 0,75m (0,035 m thickness)	plywood
22	bigger cupboard	1,8m x 1m x 2m	oak
37	smaller cupboard	1,5m x 1m x 1m	oak
34	floor	8,9 m x 6,8m x 0,0015m	pine
12	door	1,97m x 0,4m x 0,03 m	aluminum
1	floor	13m x 11m x 0,0025m	pine
6	bench	4m x 0,25m x 0,25m (0,1m thickness)	oak
55	table	2,5m x 1,27m x 0,0025m	plywood
7	projector panels	2m x 2m	cardboard
2670	pine panels for walls	1m x 0,04m x 0,005	pine
61	doors	1,97m x 0,85m x 0,037m	plywood

FIRE SIMULATION

The complete simulation of the fire propagation in the Electro-technical school “Nikola Tesla” in Niš lasted for 2400 seconds. The fire itself was simulated with burner of HRR (Heat Release Rate) from 100kW, in the square form, with dimensions of 1m x 1m. The reason for that was the fact that, especially at the pupil’s part, there were lot of desks, chairs, paper, books and similar that could be potential fire source. However, this is not the case for the laboratory part of the school where the gas bottles and similar stuff were located, which can be the source of the bigger fire. The simulation implied locating the large number of thermocouples and other simulated sensors in order to measure the biggest realized temperature in particular room and whole building. The duration of the whole simulation for one scenario at the computer was about 26 hours.

Realized simulation results present huge numerical, textual and picture form of data. In this paper, only the small parts of realized results were presented due to journal’s requirements and limitations. Numerous other results concerning the same building were presented in earlier papers [10, 11]. The examples of potential fire propagation, smoke and thermal distribution of the fire propagation at the different parts of the school are presented in Figures 7 - 13.

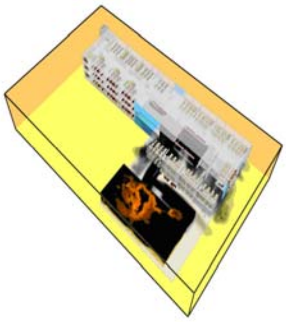

Figure 7. *The presentation of the potential fire propagation after 900 seconds at physical education hall of the ETŠ "Nikola Tesla"*

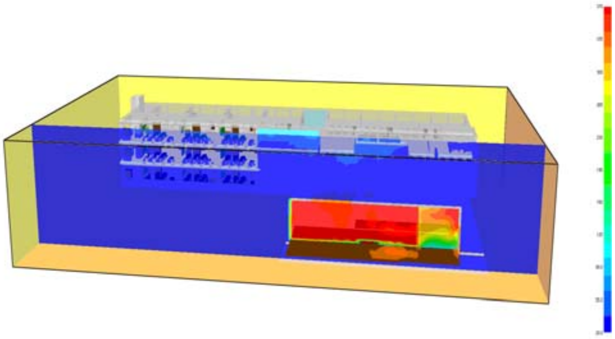

Figure 8. *The thermal distribution presentation of the potential fire propagation after 1200 seconds at school library*

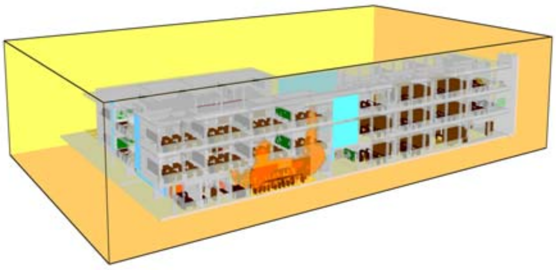

Figure 9. *The presentation of the potential fire propagation at the teacher's office of the ETŠ "Nikola Tesla" at the phase of the heat development*

Figure 10. *The presentation of the potential fire propagation at the classroom at the first floor of the ETŠ "Nikola Tesla"*

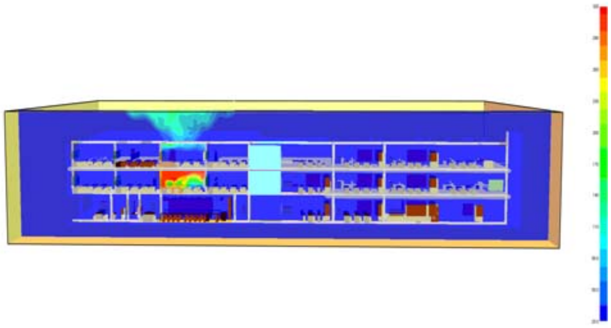

Figure 11. *The presentation of the potential fire propagation at the classroom at the second floor of the ETŠ "Nikola Tesla"*

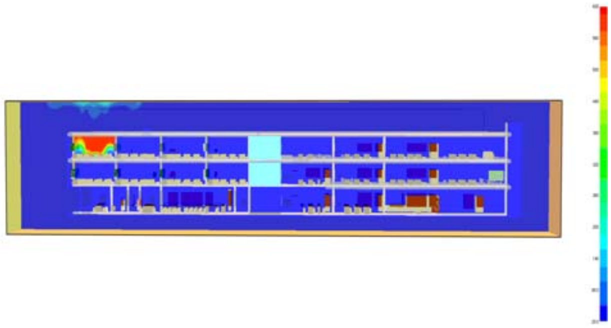

Figure 12. *The presentation of the potential fire propagation after 1000 seconds at the classroom at the second floor of the ETŠ "Nikola Tesla"*

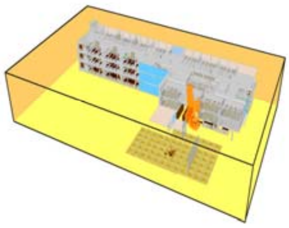

Figure 13. *The presentation of the potential fire propagation after seconds at the library of the ETŠ "Nikola Tesla"at the phase of the heat development*

THE ANALYSIS OF RESULTS

The results of the simulations showed the possible scenarios of fire propagation and smoke according to the place where the fire occurred. Different results of the fire propagation in the anterior figures were the consequence of different contents within some rooms in the school, which was expected. The fastest fire propagation and the biggest smoke contents were registered in the library and administrative rooms with big number of desks, cupboards and other elements with huge quantity of paper. It is important to note that results showed that the fire in laboratory could propagate on other rooms, which wasn't the case for other rooms. The temperatures at the first and the second floor were less then the temperatures in the library and the surrounding rooms. The simulation also showed that the smoke production would be significant knowing that the biggest part of inventory was made of wood.

As it was noted, one of the most important benefits from fire simulation was the prediction of fire propagation. According to the simulation results, it was possible to determinate the biggest values for temperatures, the possibilities of smoke generation and smoke movement, the directions of fire propagations and the speeds of fire propagations. Based on the above noted facts, it is possible to determinate the proper type of fire protection sensors, their positions and arrangement within the building, etc.

The main purpose of fire protection systems is to provide the information to the user about fire development in order to avoid human victims and material damage. Fire protection system presents very complex system that consists of many different parts that are connected into one unique system. Precision and correct work of each part of fire protection system has a crucial importance. The design of fire protection systems means the knowledge of huge numbers of facts according to the object and possible development of fire. The most important results of the projection process are the right choice of fire detector and its arrangement in the object. Although there were several ways to arrange fire detectors in a particular building (for example, triangle, strip or hexagonal), this arrangement will depend on many different factors, and, in most cases, it would be a separate example. Of course, certain rules, defined by the standards, must be respect. There are several standards according to these tasks that could be realized (NPFA 72, НПБ 88-2001, BS, DIN VDE 0833-2 and other). The most important task is to place the right types of detectors in a way that would provide fast detection and the appropriate protection. For example, possible arrangement of heat detectors in the simulation model of the ETŠ "Nikola Tesla" are presented in figure 14 (laboratory part at the second floor) while temperature results for laboratory 112, are shown in figure 15.

Figure 14. *Simulation model of the ETŠ "Nikola Tesla" (laboratory part at the second floor), with positioned heat detectors (above view)*

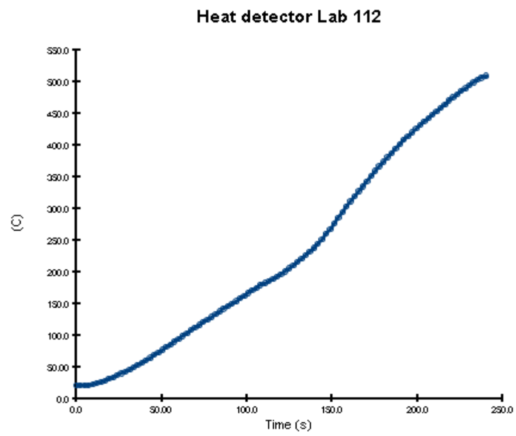

Figure 15. *Temperature results in the laboratory 112*

This arrangement provided the right time reaction of heat detectors, which was confirmed by the simulation [12].

The simulation also provides arrangement of different types of detectors (heat, smoke, flame, CO and other), composite detectors and comparing of their right time reactions.

A very important benefit provided by fire simulation, was the prediction of potential occupant's evacuation. The evacuation, generally, presents the safest, the shortest and the fastest way of movement for people, animals and material properties from endangered building or location to the secure place. At the other side, these ways should provide the possibilities for safe and fast approach of fire and medical services. The causes of evacuation could be different: fire, gas, bomb threat, earthquake, overflow, civil disorders, etc. The directions and ways for safe, fast and secure leave of the object present the evacuation routes. The evacuation routes were projected as primary and secondary. Primary evacuation route is the most frequently, route for normal communication in the building. For example, these routes could be stairs, hallways, corridors and other surfaces used for communication in object or in separate floor. They are of different dimensions for every type of building. These routes are used by fire services in case of fire. The secondary routes depend on building's purpose. These routes can be windows, roofs, etc. Both types of evacuation routes must satisfy many standards and no standard demands, according to the number of people, type and purpose of the building, speed of people moving, evacuation time necessary, etc.

The prediction of fire in the object could check the propositioned evacuation routes directly, measuring the parameters from the positioned virtual devices. PyroSim 2012 has a possibility to simulate a single room evacuation, but, what is very important, PyroSim simulation model could be exported into Pathfinder, a simulation programme developed by the same company. For example, the PyroSim 2012 simulation model exported in Pathfinder is presented in figure 15 [13].

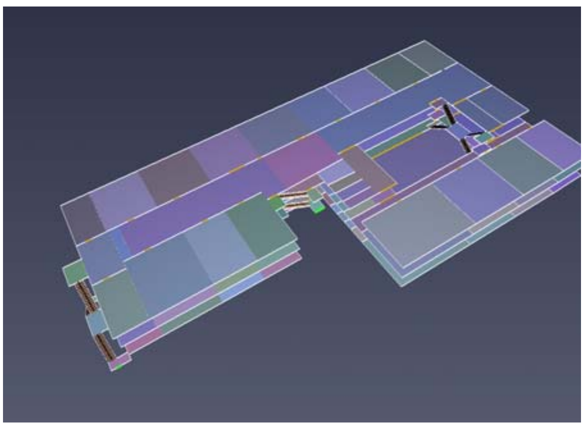

Figure 16. *ETŠ "Nikola Tesla" in Niš-Pathfinder model*

According to the type of evacuation from the building, especially interested aspects are panic and stress affects to the occupants. It is known that calm occupants have bigger chances to safely leave the building than the occupants influenced by stress and panic. In panic and stressful situations caused by fire propagation, the occupants move faster but chaotically. That implies many unexpected situations in the building. Evacuation routes have their own maximum occupant flow. That is especially important for stairs and elevators. It is very often, that in the state of panic and stress, the occupants try to get out from the building and in that way they cause tragedy. The occupant's behavior, knowledge and education, physical and psychic condition (occupant speed, panic and stress influence, moral and human qualities) should be studied in details. For example, the simulation results for 300 (100 per floor) occupants and 540 (180 per floor) occupants, randomly positioned, with movement speeds from 1m/s to 5 m/s, are presented in Figures 17 and 18 [14].

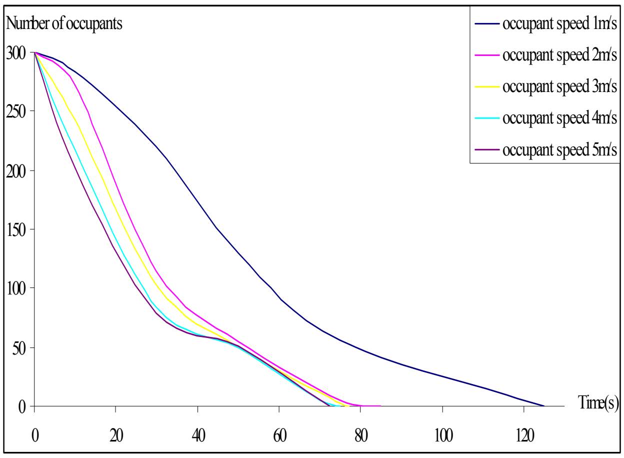

Figure 17. *Simulation results for 100 occupants per floor randomly positioned*

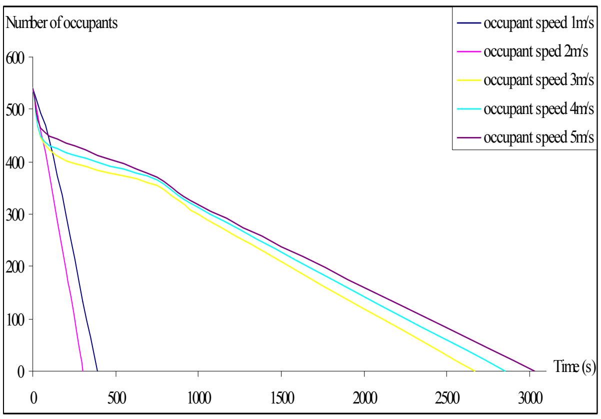

Figure 18. *Simulation results for 180 occupants per floor uniformly positioned*

These results implied the case of all exits and fire stairs available. It was possible to realize scenarios with closed or jammed doors, unavailable exit or stairs caused by fire or similar. However, these simulations provide many different scenarios for checking of existent evacuation routes and finding new in case of fire.

CONCLUSION

The simulation of fire and its consequences presents a very effective engineering tool in fire prediction, production, development and potential consequences on humans and material properties. According to the simulation results, it is possible to determine the potential directions of fire propagation, to fix and eliminate errors made during building design, which is not possible without direct testing that is rather uneconomic and hard to realize, and in many cases destructive to people and material properties. The special benefit of the simulation is the prediction of the potential evacuation routes, which is of crucial importance according to the human safety, especially in the buildings with lot of humans inside, such as schools, sanitary objects, residential objects, nurseries, etc. The results of the simulation were also important for the positions of the smoke and heat sensors, hydrants, fire protection devices, etc [16]. It is also possible to realize and compare particular standards related to detector arrangement.

The realized results present just a small part of the large investigation according to the PhD thesis "The fire and burglary protection using non- typical electrical lines", published by the University of Niš, in June 2014. The results of this and similar papers had a great influence in the calculation and projection of non-typical electrical lines used as potential line sensors for fire detection at early stage.

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BIOGRAPHY

Radoje Jevtić was born in Aleksinac, Serbia, in 1973. He received the diploma in electrical engineering for automatics and electronics from Faculty of Electronic Engineering at University of Niš, then the degree of Magister of technical sciences from Faculty of occupational safety at University of Niš, followed by PhD degree in technical sciences from Faculty of Occupational Safety, University of Niš. His main areas of research include: fire and burglary protection systems, simulations, fire and burglary sensors, etc. He is currently working as a teacher of vocational subjects in Electro-technical school Nikola Tesla in Niš.

SIMULACIJA POŽARA KAO PREDNOST PRI DETEKCIJI I ZAŠTITI OD POŽARA

Radoje Jevtić

Sažetak: *Požar predstavlja proces nekontrolisanog sagorevanja koje prouzrokuje materijalnu štetu i ugrožava ljudske živote. Važno je da poznavati brojne faktore od kojih požara zavisi u cilju uspešnog projektovanja i realizacije sistema zaštite od požara. Jedan od najefikasnijih, najekonomičnijih i najpouzdanijih načina utvrđivanja potencijalnog prostiranja požara je korišćenje programa za simulaciju. U ovom radu, predstavljena je upotreba simulatora PiroSim 2012 u određivanju potencijalnog požara. Objekat koji se koristi za simulaciju je elektrotehnička škola "Nikola Tesla" u Nišu.*

Ključne reči: požar, simulacija, programski paket za simulaciju razvoja požara - FDS, evakuacija