Izvorni znanstveni rad – Original scientific paper

Smoke detector installation in special cases - the case of an arched ceiling

Instalacija detektora dima u posebnim slučajevima - slučaj stropa u obliku luka

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Abstract

Smoke detectors are essential components of fire protection systems. Their primary function is to detect fires at an early stage and provide timely warning of their development. Therefore, the manner in which they are installed and arranged within a building is of great importance. In general, existing standards define rules for the installation and positioning of smoke detectors. Logically, these standards would prescribe identical requirements for identical types of buildings; however, in practice, this is often not the case. Differences between standards for the same building types are common, with numerous examples of such inconsistencies. This issue is even more pronounced in special cases, such as buildings with arched attics.

This paper aims to demonstrate the application of several smoke detector installation standards for such a building, together with a fire simulation conducted in PyroSim software in accordance with the VDE 0832-2 standard. The results show that, although the VDE 0832-2 standard prescribes strict rules, these rules can be adapted in the case of buildings with arched ceilings, while still achieving accurate smoke detector

Keywords: *detector, smoke, simulation, arch, attic.*

SAŽETAK

Detektori dima predstavljaju vrlo su važni uređaji u zaštiti od požara. Glavna uloga ovih detektora rano je otkrivanje i upozorenje sa ciljem predikcije požara. Prema tome, vrlo je važno kako će ovi detektori biti instalirani i raspoređeni u objektu. Generalno, postoje pravila definira-

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na standardima kako instalirati i rasporediti detektore. Bilo bi logično da ovi standardi imaju ista pravila za iste tipove objekata, ali to nije slučaj u praksi. Vrlo često, postoje razlike između standarda za iste objekte, za što postoji puno primjera. Isto je i u slučaju instalacije detektora dima u specijalnim slučajevima. Jedan od takvih slučajeva je objekt s potkrovljem u obliku luka. Ovaj je rad napisan kako bi pokazao pravila nekoliko različitih standarda za instalaciju detektora dima za spomenuti objekt sa simulacijom požara u softveru Pyrosim za konkretni objekt po standardu VDE 0832-2. Rezultati u ovom radu pokazuju, da iako standard VDE 0832-2 preporučuje stroga pravila, ova pravila se u slučaju objekata s potkrovljem mogu izmijeniti i dobiti točni rezultati u pogledu vremena reakcije detektora dima.

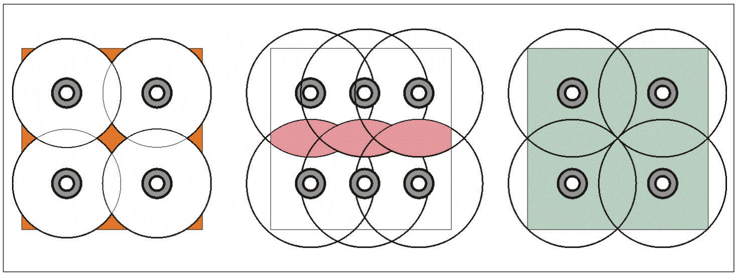
***Ključne riječi**: detektor, dim, simulacija, luk, potkrovlje*

Introduction

UVOD

Fire detectors present one of the fire protection system's most important elements. Fire is a very unpredictable and hard-to-control process; therefore, it is especially important to detect it at an early stage. That is exactly the fire detectors' role. These detectors can be classified in several ways and in various groups, depending on different demands and conditions. The most important fire detector's properties are the fire detector's response time, the fire detector's sensitivity, the fire detector's inertia, the fire detector's effect zone, etc. Fire detectors are installed in some buildings according to specific rules, defined by standards. There are several standards in use, such as EN 54:2004 (European standards), BS:2013 (British Standard), NFPA 72:2016 (National Fire Protection Association), НПБ 88-2001 (Нормы пожарной безопасности), VDE 088-2:2009 (*Verband der Elektrotechnik, originally: Association of German Electrical Engineers, now: Association for Electrical, Electronic & Information Technologies*), and others.

Smoke detectors are the most frequently used fire detectors – it is considered that more than 90 % of all fire detectors used are smoke detectors. The smoke detector's construction is based on two smoke detection principles: radioactive and optical. Their installation in the building in the first place depends on the building's surface and the supervised area of the individual smoke detector. The main rule is that the number of smoke detectors must be determined as a quotient of the noted dimensions, the same as in Blagojević (2018) and Jevtić and Blagojević (2017). According to that main rule, the fire arrangement in the room can be as it is presented in Figure 1.



a) b) c)

Figure 1. Smoke detectors arrangement in the room: a) smoke detector's arrangement with uncovered areas of the room; b) smoke detector's arrangement with redundancy, and c) optimal smoke detector's arrangement in the room.

Slika 1. Raspored detektora dima u prostoriji: a) raspored detektora dima s nepokrivenim dijelovima; b) raspored detektora dima s redundansom i c) optimalan raspored detektora dima u prostoriji.

For the installation of a smoke detector in special cases, there are special rules. One of these cases is a building with an arched ceiling. There are several standards that deal with this topic.

The European standard EN 54-14, similar to the British standard BS 5839-1, represents a rule for smoke and heat detectors, that the detector coverage semidiameter can be increased by 1 % for every 1° of roof slope, up to a maximum of 25 %. In cases of pitched roofs (roofs with more slopes), one detector should be located below every roof's top, except in cases when the difference is less than 5 % between the highest and the lowest point of the top of the roof in comparison to the height of the roof – then, the roof can be treated as a flat ceiling. Under the British standard, a roof can be treated as a flat ceiling when the noted difference is less than 150 mm for heat detectors, and less than 600 mm for smoke detectors.

The German VDE 0833-2 standard has similar detector installation rules below sloped ceilings and roofs. For the roof's slope up to 20 ° and over 20 °, special rules exist. These rules for point detectors purport, in the case when the ceiling slope is greater than 20 °, and when the surface of the supervised room is larger than 80 m^2, that the coverage area of an individual detector is 90 m^2, and 110 m^2 for heights of 6 m and 12 m. In case of the heat detectors, the surface in question is 40 m^2 for heights of 6 m, and 7.5 m for rooms larger than 30 m^2.

The installation of point smoke and heat detectors in the case of various ceiling forms is presented in Table 1. R_H presents the building height, while D_L presents the distance of the smoke detectors from the ceiling (heat detectors are installed directly at the ceiling).

Table 1. The distance between point smoke detectors at different ceiling or roof forms, under the VDE 0833-2 (Table source: Fire protection systems designing, Milan Blagojević, 2018)

Tablica 1. Udaljenost između detektora dima u različitim slučajevima oblika potkrovlja prema VDE 0833-2 (izvor tablice: Projektiranje sistema za dojavu požara, *Milan Blagojević, 2018*)

Room's height R_H	Slope of the roof α	
	angle α< 20°	angle α> 20°
	D_L	D_L
up to 6 m in height	mostly up to 0.25 m	from 0.2 m to 0.5 m
from 6 m to 12 m in height	mostly up to 0.4 m	from 0.35 m to 1 m
(from 12 m to 16 m in height) – depending on the ambient characteristics (the way of smoke spreads and develops)	from 0.25 m to 0.6 m	from 0.5 m to 1.2 m

Additionally, this standard analyses the installation of point smoke and heat detectors in special cases of ceiling forms, such as the arched ceiling, presented in Figure 2.

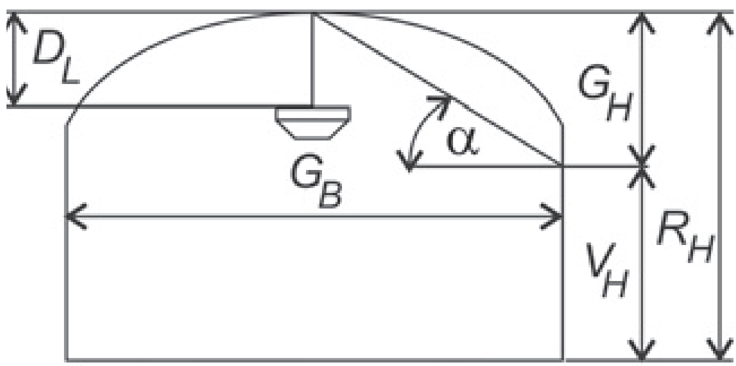


Figure 2. The smoke detector installation in the building with the arched ceiling (Figure source: Fire protection systems designing, Milan Blagojević, 2018).

Slika 2. Postavljanje detektora dima u objektu s potkrovljem u formi kružnog luka (izvor slike: Projektiranje sistema za dojavu požara, Milan Blagojević, 2018)

For these types of buildings, angle marked in Figure 1 must be calculated in the manner presented in Table 2. G_H presents the height of the round arch; G_B presents the width of the arch, while V_H presents the height of the walls, i.e., the height of the building without the ceiling or the roof.

Table 2. The way of calculating the α angle.

Tablica 2. Način računanja kuta α

The ratio between G_H/G_B	Angle α
$G_H/G_B \leq 0.2$	$\alpha \leq 20°$
$G_H/G_B > 0.2$	$\alpha \geq 20°$

The American NFPA 72 standard is simpler than the European standard on this topic. First, there is a general rule that point detectors must be installed at least 36 inches (910 mm) from the vertical plane of the roof's top. If the beams are below the roof, the ratio of the beam's depth and the ceiling's height must be observed, as well as the distance between beams and the ceiling's height. The rule purports installation of one detector in each field between the beams, if the first ratio is larger than 0.1 and the second ratio is larger than 0.4.

The Russian НПБ 88-2001 (GOST) standard does not analyse the installation of point fire detectors below the sloped roofs and ceilings in detail and mostly respects the rules of the European and British standards.

This paper aims to show the oversight regarding the installation of point smoke detectors in some special cases with respect to the said standards, so as a simulation of some and determination of reaction times of installed smoke detectors under the German VDE standard in a hangar with an arched ceiling, as a special case of point smoke detectors installation. Also, a very important aim of this paper is to show that, under the German VDE standard, in the case of a hangar with an arched ceiling, different detector height values, not only the one strictly demanded by the noted standard, can be used (Blagojević, 2018; Jevtić and Blagojević, 2018; Blagojević et al., 2018).

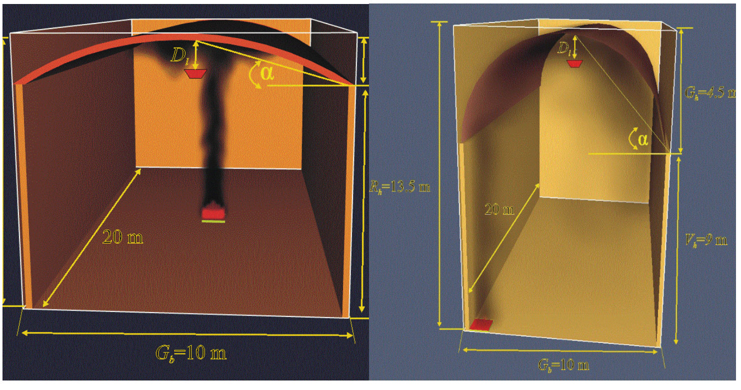
Simulation model of a building with an arched attic – *Simulacijski model objekta s potkrovljem u obliku luka*

Simulation in the study included the building with an arched attic – a model of a storage hangar. It was conducted using the simulation software Pyrosim (version 2024.2.1209, Thunderhead Engineering, USA), one of the best on the market for such cases. Walls were made from concrete (depth 20 cm). Buildings-hangars were of different arch heights and widths. There were two different building-hangar simulation models, depending on the height and angle α of the arch. The first simulation model purported a building with α ≤ 20° ($G_H/G_{B=}0.15$), while the second simulation model purported a building with α ≥ 20° ($G_H/G_{B=}0.45$). The length and width of both buildings were identical (20 m and 10 m). The heights of the buildings were different (5.8 m, 8.5 m, and 13.5 m). These heights were chosen due to the conditions described in Table 1. Since the Pyrosim software does not support complex geometry with curves and arches, arched ceilings were constructed in the AutoCAD software (V 2023 24.2, Autodesk, California, USA) and imported to Pyrosim. It is one of the most useful options of the programme, because sometimes it is very difficult to draw a building in Pyrosim. Also, it is important to note that Pyrosim and similar software require a powerful computer in terms of hardware – a strong processor, a strong graphics card, and plenty of RAM. HP ZBook Fury G8, with Intel Core i7-11850H processor, 16 x 2.5 GHz Turbo 16 x 4,8 GHz, with 32 GB RAM DDR4 and two graphic cards, Intel UHD and NVIDIA RTX A2000 (6 GB VRAM), was used. All this was done in relation to Thunderhead Engineering (2024).

Fire simulation for both simulation models was performed in the form of a burner with dimensions 1m x 1m. The fire was analysed as slow (quantity of released heat was 117 kW for 200 seconds) and ultra-fast (quantity of released heat was 7502 kW for 200 seconds). The burner's positions in both simulation models were at the beginning and in the middle of the building. Smoke detectors were located in the same way as it was described in Table 1, depending on the height of the building. The smoke detector obscuration threshold was 3,25 %/m. Regarding all noted, there were a total of 76 simulations per case.

The main comparison criterion was the smoke detectors' heights. Therefore, the simulation was performed for the height recommended by the German VDE 0833-2 standard, as well as for other heights, higher or lower than those recommended.

Both simulation models, with marked dimensions and the burner's positions, are presented in Figure 3 (a, b).



a) b)

Figure 3. Simulation models with marked dimensions and with a smaller angle α and a burner at the middle of the building (a), and a bigger angle α and a burner at the beginning of the building (b)

Slika 3. Simulacijski modeli s označenim veličinama i s manjim uglom α i plamenikom na sredini objekta (a) i s većim uglom α i plamenikom na početku objekta (b)

Results – *Rezultati*

The simulation results, with several moments of fire and smoke spreading in the simulated buildings, are presented in Tables 3 to 8, and in Figures 4 and 5. The RTC mark (reaction time of the closest detector) in the Tables marks the reaction time of the closest detector [s], while the RTF mark (reaction time of the farthest detector) marks the reaction time of the farthest detector [s]. The green colour in the Tables marks the detector's height that should be used under the German VDE 0833-2 standard.

Table 3. Simulation results for a building with an arched angle α < 20° and a height of 5.8 m.

Tablica 3. Simulacijski rezultati za objekt s kutom luka α < 20° i visinom od 5,8 m.

Building with dimensions 10 x 20 x 5.8, $G_H/G_{B=}0.15$							
Height of the smoke detectors D_l		Height 0.25 m		Height 0.4 m		Height 0.6 m	
Fire type	Burner position	RTC	RTF	RTC	RTF	RTC	RTF
Slow fire	at the beginning of the building	50.4	99.4	51.7	99.7	53.5	100.5
	in the middle of the building	48.4	49.5	55.3	56.7	54.3	55.4
Ultra-fast fire	at the beginning of the building	24.6	39.5	24.5	41.6	24.7	43.6
	in the middle of the building	22.5	25.5	23.1	25.6	23.4	25.9

Table 4. Simulation results for a building with an arched angle α < 20° and a height of 8.5 m.

Tablica 4. Simulacijski rezultati za objekt s kutom luka α < 20° i visinom od 8,5 m.

Building with dimensions 10 x 20 x 8.5, $G_H/G_{B=}0.15$							
Height of the smoke detectors D_l		Height 0.25 m		Height 0.4 m		Height 0.6 m	
Fire type	Burner position	RTC	RTF	RTC	RTF	RTC	RTF
Slow fire	at the beginning of the building	55.7	110.3	56.4	111.3	56.7	118.9
	in the middle of the building	50.6	53.7	52.7	53.8	55.8	57.7
Ultra-fast fire	at the beginning of the building	25.6	45.7	26	48.8	25.9	52.9
	in the middle of the building	23.4	26.4	24.7	26.7	25.9	26.9

Table 5. Simulation results for a building with an arched angle α < 20° and a height of 13.5 m.

Tablica 5. Simulacijski rezultati za objekt s kutom luka α < 20° i visinom od 13,5 m.

Building with dimensions 10 x 20 x 13.5, $G_H/G_{B=}0.15$							
Height of the smoke detectors D_l		Height 0.25 m		Height 0.4 m		Height 0.6 m	
Fire type	Burner position	RTC	RTF	RTC	RTF	RTC	RTF
Slow fire	at the beginning of the building	61.6	131.4	63.5	135.7	65.3	138.8
	in the middle of the building	50.7	55.7	51.5	56.9	52.7	57.3
Ultra-fast fire	at the beginning of the building	32.1	49.7	32.3	54.6	32.5	59.2
	in the middle of the building	31.5	45.9	31.9	46.2	32.2	47.3

Table 6. Simulation results for a building with an arched angle α > 20° and a height of 5.8 m.

Tablica 6. Simulacijski rezultati za objekt s kutom luka α > 20° i visinom od 5,8 m.

Building with dimensions 10 x 20 x 5.8, $G_H/G_{B=}0.45$							
Height of the smoke detectors D_l		Height 0.3 m		Height 0.5 m		Height 0.8 m	
Fire type	Burner position	RTC	RTF	RTC	RTF	RTC	RTF
Slow fire	at the beginning of the building	74.4	114.5	76.4	116.7	77.3	117.5
	in the middle of the building	50.5	50.9	52.4	52.9	53.3	53.7
Ultra-fast fire	at the beginning of the building	25.9	48.8	26.8	49.3	28.1	49.9
	in the middle of the building	25.5	26.4	26.8	27.8	27.9	29

Table 7. Simulation results for a building with an arched angle α > 20° and a height of 8.5 m.

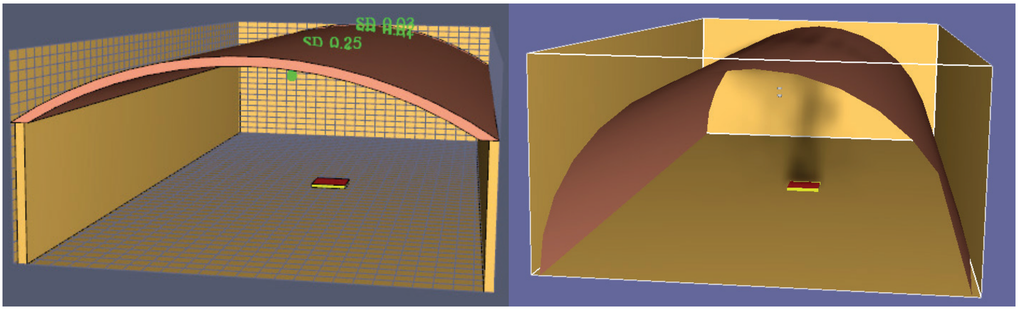
Tablica 7. Simulacijski rezultati za objekt s kutom luka α > 20° i visinom od 8,5 m.

Building with dimensions 10 x 20 x 8.5, $G_H/G_{B=}0.45$							
Height of the smoke detectors D_l		Height 0.3 m		Height 0.5 m		Height 0.8 m	
Fire type	Burner position	RTC	RTF	RTC	RTF	RTC	RTF
Slow fire	at the beginning of the building	76.7	116.8	77.9	117.8	78.6	118.4
	in the middle of the building	52.4	53	53.7	54.6	54.4	55.3
Ultra-fast fire	at the beginning of the building	31.6	50.4	32.5	52.4	33.2	53.3
	in the middle of the building	26.3	27.2	27.6	28.6	28.7	29.8

Table 8. Simulation results for a building with an arched angle α > 20° and a height of 13.5 m.

Tablica 8. Simulacijski rezultati za objekt s kutom luka α > 20° i visinom od 13,5 m.

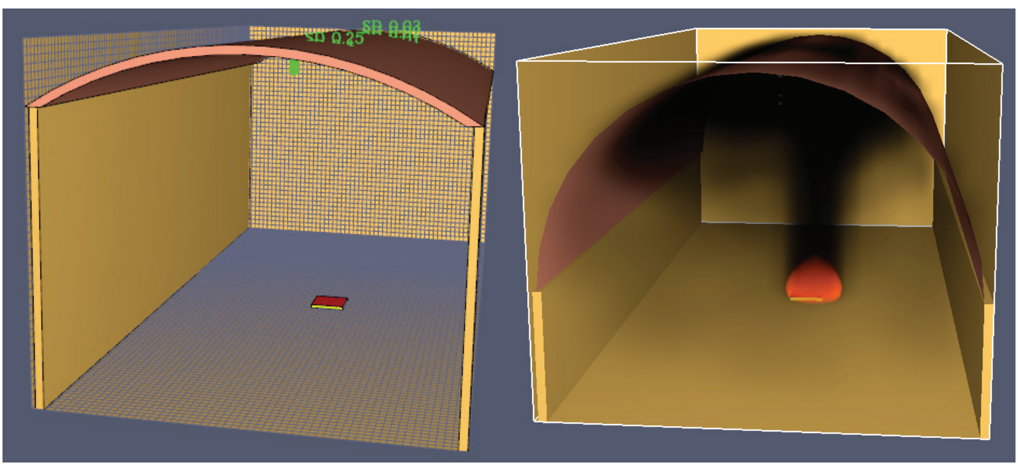
Building with dimensions 10 x 20 x 13.5, $G_H/G_{B=}0.45$							
Height of the smoke detectors D_l		Height 0.3 m		Height 0.5 m		Height 0.8 m	
Fire type	Burner position	RTC	RTF	RTC	RTF	RTC	RTF
Slow fire	at the beginning of the building	77.8	121.4	79.4	124.5	81.9	127.2
	in the middle of the building	56.6	58.7	56.8	59	57	59.1
Ultra-fast fire	at the beginning of the building	32.7	51.4	33	53.6	34.9	55.6
	in the middle of the building	27.4	28	28.6	29.8	29.9	30.9



a) b)

Figure 4. Simulation model of the building with a smaller angle α, a burner at the middle of the building, and a height of 5.8 m and marked burner's positions (a), and the building with a larger angle α, a burner at the middle of the building and a height of 5.8 m (b)

Slika 4. Simulacijski model objekta s manjim uglom α, plamenikom na sredini objekta i visinom od 5,8 m i označenim pozicijama plamenika (a) i objekta s većim kutom, plamenikom na sredini objekta i visinom od 5,8 m (b)



a) b)

Figure 5. Simulation models of the building with a smaller angle α, a burner positioned at the middle of the building, and a height of 8.5 m, and marked burner's positions (a) and the building with a larger angle α, a burner at the middle of the building, and a height of 8.5 m (b)

Slika 5. Simulacijski modeli objekta s manjim kutom α, plamenikom na sredini objekta i visinom od 8,5 m i označenim pozicijama plamenika (a) i objekta s većim kutom, plamenikom, na sredini objekta i visinom od 8,5 m (b)

The simulation results for the first simulation model, with angle $\alpha < 20°$, showed very slight differences with respect to the height of the building, regardless of the height of the building (Tables 3 to 5). Of course, it was expected that differences in times between the closest and the farthest smoke detectors were greater in the case where the burner was at the beginning of the building, next to the building where the burner was in the middle of the building. A very important fact that should be noted is the manner in which the smoke spreads in relation to the ceiling and its form (as presented in Figure 3 b). Also, there is a very slight difference between the detector's height from the ceiling (only a few seconds), implying that the heights determined by the standard are not that important to respect (it will not be a mistake to use a different smoke detector height, although the standard recommends another). Results were confirmed for both types of fires (slow and ultra-fast).

The simulation results for the second simulation model, with angle $\alpha > 20°$, showed very slight differences with respect to the height of the building, regardless of the height of the building and the fact that the detectors were installed slightly higher (Tables 6 to 8). Generally, reaction times are slightly longer in comparison to the first simulation model (which was expected), but the results showed almost the same situation. So, including in this case, it will not be a mistake to use a different smoke detector installation height – higher or lower, although the standard recommends another height; therefore, designers may make small adjustments within the limits allowed by the standards, if these are confirmed by a simulation or an experiment.

Conclusion

ZAKLJUČAK

Smoke detectors present one of the crucial elements in fire protection systems. Their timely reaction presents the most important information for the fire protection systems. In order for them to react in a timely manner, they must be installed properly. The fire detector installation is regulated by valid standards. Simulated models, which presented different variations of building with the arched ceiling, through the simulations performed, showed that, although the applicable standard recommends strict smoke detector height values, it will not be a mistake to use a different smoke detector height value (for example, it is not mistake to use smoke detectors with heights D_l of 0.3 m, 0.5 m or 0.8

m (any of them) for building with the height of 13.5 m and a wider angle α, although the VDE 0833-2 standard recommends 0.8 m). Also, the results have been confirmed for both types of fires (slow and ultra-fast fires).

In this particular case, the results showed that designers do not have to strictly adhere to everything stated in the standard, but can make small changes, especially when some other conditions demand a slightly different practical solution, in the sense of structural or architectural demands. Some future investigation should be directed regarding the simulation results of different standards. Of course, it is very important to note that every similar hypothesis must be proved either by an experiment or a simulation. Similar findings were reported by Jevtić and Janković (2023), Jevtić and Janković (2022), Xu et al. (2021), and Hwang et al. (2023), who also observed responses for smoke detection in different fire cases.

The use of simulation software presents a mandatory procedure for the modern design of fire protection systems. Modern simulation software presents a mandatory tool for engineers for a number of reasons and posses-sses many different important benefits (precise work and analysis, safety work without any kind of risk for human life, much lower costs for adequate real experiment, etc.). Use of simulation software can indicate many different directions, many problems, many solutions and other things related to fire and smoke spreading, fire detectors arrangement, measuring of fire detector reaction time, etc.

Of course, it is very important to note that the main limitation of this study was that simulations were performed on idealised models without experimental verification and with only two different fire types (slow and ultra-fast) and a single type of smoke detector analysed (photoelectric smoke detectors). A similar future investigation would include a simulation with different fire types and different smoke detector types, potentially with experiment confirmation.

Izjava o sukobu interesa:

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