N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 444 (2020), 75 – 82 **https://doi.org/10.32014/2020.2518-170X.133**

UDC 614.841.2

Sergiy Yemelyanenko, Andriy Ivanusa, Roman Yakovchuk, Andriy Kuzyk

Lviv State University of Life Safety, Lviv, Ukraine.
E-mail: yemelyanenko@ldubgd.edu.ua, Ivaaanusa@gmail.com,
yakovchukrs@ukr.net, andrij_k@yahoo.com

FIRE RISKS OF PUBLIC BUILDINGS

Abstract. The complex research method is used in the work, which includes: analysis and generalization of scientific achievements in the field of fire safety, application and processing of statistical data; application as analytical methods of research by collecting, generalizing and analyzing the current normative documents of the State Emergency Service of Ukraine and statistical methods of probability theory, geospatial, mathematical modeling, methods of system analysis.

Research Object: The risk of death from fire in public buildings and structures.

The purpose of the work is risk evaluation of death from fires in public buildings.

Research methods. The complex method of researches is used in the work, which includes: analysis and application of statistical methods of data processing, verification of reliability of the obtained results, mathematical modeling and other analytical methods.

The concept of the risk is described in the article and the main normative documents are outlined that treat them. The basic methods and methods of risk assessment for public buildings are analyzed.

Fire risk assessment is the calculation of individual fire risk for residents, staff and visitors in a public building. The numerical expression of an individual fire risk is the frequency of exposure of hazardous fire factors to a person in a building or structure. The frequency of exposure to hazardous fire factors is determined for fire-hazardous situations, which are characterized by the greatest danger to the life and health of people in the building.

The CFAST program simulated the occurrence of limit concentrations of hazardous factors during fires for two typical public buildings. It is also suggested how to evaluate the results on a specific color scale that allows you to create risk maps for visualization. The draft methodology proposes to consider the follow-up time of fire and rescue units when determining the evacuation time.

The main methods and methodologies of risk assessment for buildings and public facilities have been analyzed. For two facilities, the risk of death from fire in buildings and facilities has been estimated. The results of evaluation have been suggested in a color scale, which allows creating maps to visualize the risks. The simulation of the limit concentrations of hazardous factors during the fires for two typical public facilities has been done in CFAST software.

Mapping the risks of death from a fire in the appropriate group in the appropriate colors allows you to build a map of the risks of death from a fire and fire and rescue workers know the possible risks and dangers of the objects.

The start time of the evacuation, in the absence of warning systems, is determined depending on the time the fire and rescue units follow to the fire site.

The proposed calculation methodology and visualization tools allow the rescuer, who makes the decision, to comprehensively assess the situation during the design and to avoid the possible consequences of an emergency, which will increase the level of security.

Key words: risk, hazardous factors, CFAST, integrated model, public buildings, mapping.

Introduction. According to the annual fire statistics data from the departments of the State Emergency Service (SNS) of Ukraine, the situation with fires in public buildings in Ukraine is complicated. More than 60 thousand fires are registered in Ukraine annually. 2-3 thousand people die in fires. Such significant number of fires and deaths requires application of new approaches to fire hazard assessment and reduction, particularly risk-oriented ones.

At the beginning of the new millennium, a concept of "safety culture" [1] emerged and has been successfully developing. It grounds on educating responsibility of people for their safety in all spheres of their activity. Undoubtedly, safety is one of the most important conditions of a human life and the most important principle of society's existence. In the course of any human activity there is always a danger factor, so for many years, the European Union members and other advanced countries of the world have been focusing attention on security issues. In order to increase the level of safety, scientifically based prognostication methods and principles of risk management in the main areas of human activity have been developed.

Risk is a probabilistic value that allows evaluation and recognition of unwanted events that may occur. In [2], risk is a quantitative characteristic of the possibility of a particular hazard occurrence or its consequences, which is measured in corresponding units of measurement. Each hazard can be characterized by many different risks that assess the various aspects and parameters of this hazard: for example, on the one hand, the frequency of its occurrence, on the other, the nature and extent of the consequences of the danger.

Subject of research: Risks of death from fires in public buildings and facilities.

The purpose of the paper is to assess the risk of death from fires in public buildings and facilities.

Materials and Methods. A complex method of research is used in the paper, which includes: analysis and application of statistical methods of data processing, verification of the reliability of the results, mathematical modeling and other analytical methods.

To calculate the risks based on the available methodology [3, 4], the company "Sitis" has designed software to calculate the value of individual fire risk, namely: "Sitis: FLOUTEK VD", "Sitis: BLOCK", "Sitis: VIM" and "Sitis: Sprint" [4], "EPOS: Indeline 1.01". They provide an opportunity to identify the main factors of a fire to assess fire risks in buildings and facilities, in particular, those which are aimed for public usage.

PyroSim [5] is software with a user-friendly graphical interface to model the dynamics of the development of hazardous fire factors by field-based method of Fire Dynamics Simulator (FDS).

The FDS (Fire Dynamics Simulator) software [6] implements a calculated hydrodynamic model of heat and mass transfer during combustion. FDS solves the Navier-Stokes equation for low-velocity temperature-dependent flows. Particular attention is paid to the spread of smoke and heat transfer during the fire.

Smokeview [7] is software that reproduces FDS results in the form of animated images. The software can visually simulate fire and smoke. The three-dimensional representation of the physical model makes it possible to estimate the visibility within the depicted premises.

The CFAST model [8] is designed to assess the dynamics of fire hazards in residential, public and industrial buildings and facilities. Also, the model can be used to determine the design parameters of fire systems – natural or artificial anti-smoke ventilation, fire alarm. The mathematical model of CFAST grounds on the Cauchy problem for a system of ordinary differential equations. The system includes the equation of conservation of mass, energy (the first law of thermodynamics), the ideal gas law, the ratio of density to internal energy [8].

Results and Discussion. Risk assessment includes risk analysis, which in turn consists of the following steps:

1. identification of hazard (threats, possible undesirable events, sources);
2. vulnerability analysis (causes, consequences);
3. description of the risk by using probabilities and expected values.

When analyzing fire hazards of the facility under protection, it is necessary to identify and analyze all the fire risks inherent in the object first, then evaluate their current values, determine the permissible values for all fire risks and adopt the necessary technological solutions for risk management.

After that, it is necessary to select or develop methods and technologies to manage each risk, use them and thus provide the fire safety of the facility under protection.

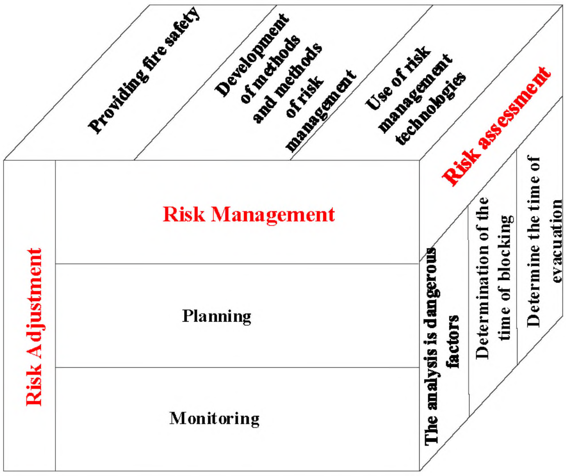

Figure 1 – Risk management and assessment

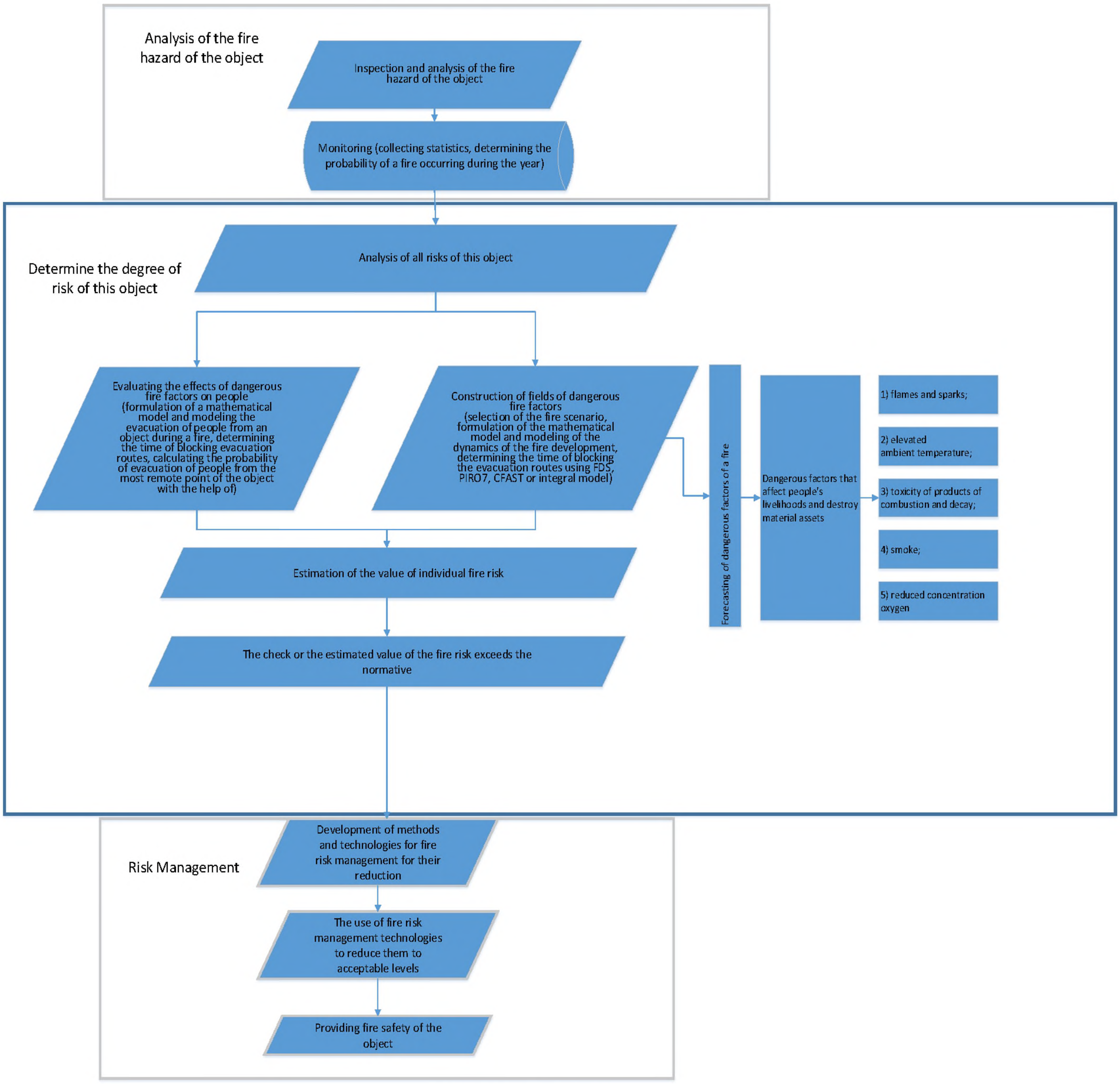

Figure 2 – Risk management

The action plan is developed and the priority of management decisions for risk reduction is determined.

Different gradations are used for risk assessment: insignificant, acceptable, high, and unacceptable. Acceptable risk is often used along with the term a reasonable risk. When the system has criteria of unacceptable risk then measures or technological solutions are introduced to reduce the level of risk to an acceptable level.

The EN 954-1 regulations define five levels of protection (B, 1, 2, 3, 4) that relate to 5 risk classes associated with 3 unprotected risk characteristics:

The calculation of fire risks is carried out separately for each group of public buildings.

The Methodology for determining the fire risk in buildings and facilities of various classes of functional fire hazard [3] is applied to calculate the risk of death from fires. It contains analytical methods for determining the individual risk of death from fires and verification of compliance with the permissible values, is used, if:

$$Q_b \leq Q_h, \tag{1}$$

the statistical value of the individual fire risk of death in a fire, $Q_h=10^{-6}$ dead people / (people · per year) – normative value for the facility, and Q_b – estimated value of the individual fire risk of death in a fire. In case there are fire prevention measures in a public building, the individual fire risk Q_b is calculated by the formula

$$Q_b = Q_n \cdot P_{pr}(1 - P_e)(1 - P_{p.z.}) \tag{2}$$

Q_n – average value of probability of a fire in a public building of a certain class during a year; P_{pr} – the probability presence of people in the building; P_e – the probability evacuation of people from the building; $P_{p.z.}$ – coefficient for the compliance with fire protection aimed at ensuring safe evacuation during a fire with regulatory requirements for fire safety.

The time of occurrence of hazardous fire factors has been calculated by the integrated model according to the methodology.

According to the integrated model of the methodology, it is believed that a fire occurs in the room next to the main evacuation exit – in the office of a warden. Fire load – office furniture, paper documentation and carpet (Article 66 Appendix 7 of Methodology database of typical fire load – Furniture + paper (0,8) + carpet (0,2)). Room dimensions: 6x4,2x2,4 m. The room has access from the corridor and from another room. Doors have access from the corridor by which the evacuation is done through the main exit. The fire occurs when the children are in their groups in the sleeping quarters, which are located most distantly from the evacuation exits.

The received results:

- for the t_{cr} O_2 = 25,37 c;
- for the CO – t_{cr} CO = 31,35 c;
- for the HCL – t_{cr} HCL = 38,44 c.

Since the integral model makes it possible to determine the hazardous factors of a fire only for one room without spreading it to others, CFAST two-zone model is used to determine the dangerous factors of a fire in a kindergarten. It simulates fires in buildings more efficiently than an integral one and defines the maximum time of occurrence of fire hazardous factors, which allows determining the required time of the fire and rescue units to arrive to the scene of call and the necessary evacuation time to ensure safety of people [8].

According to the calculation results:

- limited visibility in the cabinet 1 with the seat of the fire and the adjacent room (storeroom 1) will come within 0,25 min after the start of a fire, and a decrease in the concentration of oxygen limit values in the storeroom 1 will come in 1,5 min;
- limited visibility on staircase 1 and staircase 2 will occur in 1,7 and 2,5 min respectively;
- hazardous temperature values on the premises of the seat of the fire will come in 1,2 min, and in the storeroom 1 in 1,5 min.

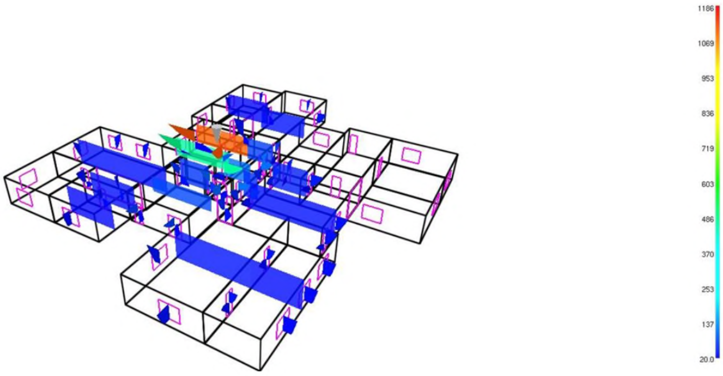

Figure 3 – Development of fire in the office 1

Therefore, among the hazardous fire factors, limited visibility will occur the most quickly, so evacuation from the 2nd floor of the kindergarten building through the staircase is impossible already after 1,7 min (staircase 1) and 2,5 min (staircase 2). Limited visibility in corridor 1 and corridor 2 will occur in 1,25 min.

One of the main problems is the state of fire protection of public buildings, in particular, those of cultural and educational domains. Therefore, we consider in detail the public building aimed at various leisure activities "Lviv State Palace of Aesthetic Education of Youth".

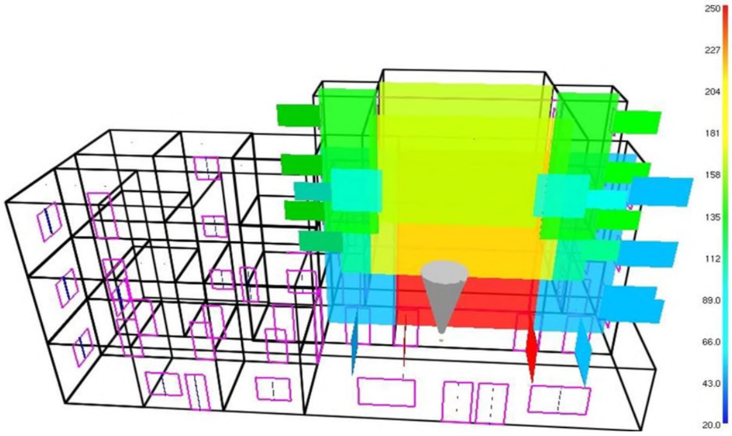

Figure 4 – Time layout of dangerous fire factors in the auditorium
of the Lviv State Palace of Aesthetic Education of Youth

Grounding on the results of calculations, the following has been determined:

1. The medium temperature on the stage will be 260 ºC, in the auditorium 1 – 209 ºC (within 3.8 min in the upper part of the room and 7 min in the lower part of the room), and in the auditorium 2 – 189 ºC (within 4,2 min in the upper part of the room and 7,7 min in the lower part of it).

2. The lack of oxygen will occur on the stage in 6,5 min, in the auditorium 1 – in 7 min, in the auditorium 2 – in 7,2 min, in the staircases 4 and 5 – in 9,5 min, and in the corridors 2 and 3 – in 10 min

3. Limited visibility will occur: on the stage in the upper part of it in 15 seconds and in 2,1 min in the bottom of the room; in the auditorium 1 in its upper part in 16 seconds and in 2,5 min in the bottom of the room; in the auditorium 2 in its upper part in 17 seconds and in 2,6 min in the bottom of the room; in the corridors 2 and 3 in the lower part of it will occur in 2,9 min; in the upper part of the staircases 4 and 5 in 2,1 min and in 2,9 min in the lower part of them (see figure 5).

Therefore, limited visibility will occur the most quickly, so it is necessary to evacuate auditorium 1 and 2 in 2,5 min, to pass through staircases 4 and 5 and corridors 2 and 3 is within 2,9 min. The lack of oxygen in the corridors and staircases will occur in 9,5 and 10 min, respectively.

The calculation of the value of individual fire risk in a kindergarten building has been carried out for this scenario according to the Methodology formula [3].

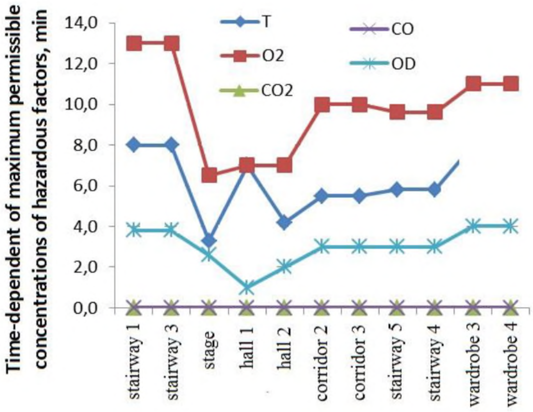

Figure 5 – Time layout of maximum permissible concentrations of hazardous factors and limited visibility in case of fire in the Lviv State Palace of Aesthetic Education of Youth

In the case of open doors from the room of the warden Q_b = 1·10^{-4}, which exceeds the normative value of risk Q_{bh}= 10^{-6}.

Ultimately we get that Q_b = 9,09·10^{-8} conditions of the closed door from the room of the warden, which does not exceed the normative value of risk Q_{bh} = 10^{-6}.

Thus, the use of fire doors can reduce the value of fire risk and ensure timely evacuation. The arrangement of fire alarm systems and anti-smoke protection will allow the timely start of evacuation and its successful procedure.

The calculation of the value of individual fire risk in the building of the Lviv State Palace of Aesthetic Education of Youth has been carried out for this scenario according to the Methodology formula [3].

Finally, we get that Q_b = 9,3·10^{-5}, which exceeds the normative value of risk Q_{bh} = 10^{-6}.

Consequently, the individual fire risk exceeds the permissible value, therefore there is a need to develop additional fire prevention measures. For example, it can be equipped with a fire alarm and a fire curtain to detect a fire and put into operation a fire curtain in the auditorium. Their usage will reduce the individual fire risk by promptly informing employees about the fire, which will facilitate safe evacuation and accelerate the arrival of firefighting units to the scene of fire.

Given the closed fire curtain of the stage room, we get that Q_b = 9,1·10^{-8}, which does not exceed the normative value of risk Q_{bh} = 10^{-6}. Consequently, the use of a fire curtain can reduce the value of fire risk and timely evacuation. The arrangement of fire alarm systems and fire curtains will allow the timely start of evacuation and successfully carry it out.

Scale of individual fire risk assessment for public buildings

Color [12]	Proposed actions	Level of risk [2, 9-11]	Value
Red	Danger. Immediately take security measures	Unacceptable risk	$\geq 5 \cdot 10^{-4}$
Orange	Very careful. Perform appropriate security measures	High risk	$5 \cdot 10^{-5} \div 5 \cdot 10^{-4}$
Yellow	Carefully. Prepare for appropriate security measures	Acceptable risk	$10^{-6} \div 5 \cdot 10^{-5}$
Green	Security. No action is required	Insignificant risk	$\leq 10^{-6}$

The obtained values of individual fire risk in groups of public buildings are suggested to be evaluated on the scale [2, 9-11] and the main color codes and levels of severity of risks [12], where the orange color (High Risk) is added, which allows outlining the risk limits more precisely and adapting to generally acceptable levels of risk [2, 9-11]. This scale is depicted in the form of table by setting the corresponding colored denotations.

Conclusions:

1. As a result of the calculations carried out according to the Methodology, it has been established that the individual fire risk in the Lviv State Palace of Aesthetic Education of Youth exceeds the

permissible value and makes $Q_b = 9{,}3 \cdot 10^{-5}$, therefore there is a need to develop additional fire prevention measures. For example, the stage should be equipped with a fire curtain to protect the auditorium.

2. By reducing the risk of death from fire to $Q_b = 9{,}1 \cdot 10^{-8}$, it is possible to reduce the evacuation time, which is achieved by using a fire curtain and a fire alarm system in the stage premises of the Lviv State Palace of Aesthetic Education of Youth.

3. The estimated design values of individual fire risk for public buildings are proposed to be evaluated according to the generally accepted scale of the World Health Organization and the main color codes and severity levels established by ISO 22324: 2015, IDT Societal security – Emergency management – Guidelines for colour-coded alerts.

4. The results of the paper are used in the educational process of the Lviv State University of Life Safety within the course "Fire Risks of Critical Infrastructure", which is taught to graduate students majoring in Fire Safety and can be used to prepare normative documents for fire risks assessment.

С. Емельяненко, А. Ивануса, Р. Яковчук, А. Кузык

Львов мемлекеттік тіршілік қауіпсіздігі университеті, Львов, Украина

ҚОҒАМДЫҚ ҚЫЗМЕТТЕГІ ҒИМАРАТ ПЕН ҚҰРЫЛЫСТАҒЫ ӨРТ ҚАТЕРІ

С. Емельяненко, А. Ивануса, Р. Яковчук, А. Кузык

Львовский государственный университет безопасности жизнедеятельности, Львов, Украина

ПОЖАРНЫЕ РИСКИ ЗДАНИЙ И СООРУЖЕНИЙ ОБЩЕСТВЕННОГО НАЗНАЧЕНИЯ

Аннотация. В работе использован комплексный метод исследований, включающий в себя: анализ и обобщение научных достижений в сфере пожарной безопасности, применение и обработки статистических данных; применение аналитических методов исследований путем сбора, обобщения и анализа действующих нормативных документов Государственной службы Украины по чрезвычайным ситуациям и статистические, методы теории вероятностей, картографии, математическое моделирование, методы системного анализа.

Объект исследований: риски гибели от пожаров в зданиях и сооружениях общественного назначения.

Целью работы является оценка рисков гибели от пожаров зданий и сооружений общественного назначения.

Методы исследования. В работе использован комплексный метод исследований, включающий в себя: анализ и применение статистических методов обработки данных, проверка достоверности полученных результатов, математического моделирования и других аналитических методов.

В работе раскрыто понятие риска и указаны основные нормативные документы, которые трактуют их. Проанализированы основные методы и методики оценки рисков для зданий и сооружений общественного назначения.

Оценка пожарного риска заключается в расчете индивидуального пожарного риска для жителей, персонала и посетителей в здании или сооружении общественного назначения. Числовым выражением индивидуального пожарного риска является частота воздействия опасных факторов пожара на человека, находящегося в здании или сооружении. Частоту воздействия опасных факторов пожара определяют для пожароопасных ситуаций, которые характеризуются наибольшей опасностью для жизни и здоровья людей в здании.

С помощью программы CFAST выполнено моделирование наступления предельных концентраций опасных факторов при пожарах для двух типовых объектов.

Полученные значения индивидуального пожарного риска по группам общественных зданий предлагается оценивать по соответствующей шкале и по основным цветным кодам и уровням тяжести рисков, где добавлен оранжевый цвет (высокий риск), что позволяет более точно очертить границы риска и адаптировать к обще-приемлемым уровням риска.

Прогнозирование пожарных рисков реализуется на основе предложенной методики расчета пожарных рисков. Для визуализации расчета пожарных рисков погибнуть от пожара для общественных зданий предлагается использовать графические редакторы.

Нанесение на карту рисков погибнуть от пожара в соответствующей группе в соответствующих цветах позволяет построить карту рисков гибели от пожара и работникам пожарно-спасательной службы знать возможные риски и опасности объектов.

Время начала эвакуации, при отсутствии систем оповещения, определять в зависимости от времени следования пожарно-спасательных подразделений к месту пожара.

Предложенная методика расчета и средства визуализации позволяют спасателю, который принимает решение, комплексно оценить обстановку при проектировании и избежать возможных последствий чрезвычайной ситуации, что позволит повысить уровень безопасности.

Ключевые слова: риск, опасные факторы, CFAST, интегрированная модель, общественные здания, картографирование.

Information about authors:

Yemelyanenko Sergiy, Lviv State University of Life Safety, Lviv, Ukraine; yemelyanenko@ldubgd.edu.ua; https://orcid.org/0000-0002-2766-8428

Ivanusa Andriy, Lviv State University of Life Safety, Lviv, Ukraine; Ivaaanusa@gmail.com; https://orcid.org/0000-0001-9141-8039

Yakovchuk Roman, Lviv State University of Life Safety, Lviv, Ukraine; yakovchukrs@ukr.net; https://orcid.org/0000-0001-5523-5569

Kuzyk Andriy, Lviv State University of Life Safety, Lviv, Ukraine; andrij_k@yahoo.com; https://orcid.org/0000-0003-0118-9493

REFERENCES

[1] Concept of risk management of emergencies of technogenic and natural character. http://www.mns.gov.ua/content/education_kurns.html

[2] Brushlinskiy N.N., Gluhovenko Y.M., Korobko V.B. «Fire risks. Basic concepts» Bulletin of the National Academy of Sciences of Fire Safety, 2004. 47p.

[3] The method of determining the calculated value of fire risk in buildings, structures and structures of various classes of functional fire hazard: approved. 06.30.2009 by the order of the Ministry of Emergency Situations of Russia No. 382: reg. in the Ministry of Justice of the Russian Federation 06.08.2009, reg. No. 14486: enter 06/30/2009. M.: FGU VNIIPO EMERCOM of Russia, 2009.

[4] Building Information Technologies and Systems Ltd. "Sitis" http://www.sitis.ru

[5] Sitis User's Guide http://sitis.ru/media/documentation/PRS-RP-2012-1.pdf

[6] FDS (Fire Dynamics Simulator) http://fds.sitis.ru/docs/FDS_5_User_Guide.pdf

[7] Smokeview http://fds.sitis.ru/docs/SMV_5_User_Guide.pdf

[8] CFAST – Consolidated Model of Fire Growth and Smoke Transport (Version 6), *Software and Experimental Validation Guide*. Chapters 5-11, 5036-5-1 RU National Institute of Standards and Technology U.S. Department of Commerce, 2008. 54 p.

[9] Susan Rose, Stephanie Flamberg, Fred Leverenz, Guidance Document for Incorporating Risk Concepts into NFPA Codes and Standards, Massachusetts, 2007. 125 p.

[10] Jonkman S.N., van Gelder P.H.A.J.M., Vrijling J.K. «An overview of quantitative risk measures for loss of life and economic damage», Journal of Hazardous Materials, 2002, A99. P. 1-30.

[11] ALARP "at a glance" http://www.hse.gov.uk/risk/theory/alarpglance.htm

[12] ISO 22324:2015 Societal security – Emergency management – Guidelines for colour-coded alerts

[13] Chernov S.K. «Risk management system in organizational projects» Bulletin of the National University of Shipbuilding, Mykolaiv: NUS, 2006. N 2. P. 163-168.

[14] Yemelyanenko S., Rudyk Y., Ivanusa A. Geoinformational System for Risk Assessment Visualization CSIT, 2018, 1. P. 17-20.

[15] Mechanism of Fire Risk Management in Projects of Safe Operation of Place for Assemblage of People. 2017. Vol. 1. P. 305-308.

[16] Gulida A.M., Bashinskiy O.I., Movchan I.O. Fire safety: Collection of scientific works, Lviv: LDU BZD, 2012. N 20. P. 150-154.

[17] Ivanusa A. «Project of forming «culture and safety» of the airport», MATEC Web of Confer-ences, 2018. Vol. 247. 00045.

[18] Shilds D., Boys K.I., Holshchevnikov V.V., Samoshyn D.A. «Fire explosion safety», 2005, 1. P. 44-52.

[19] Iskakbayev A.I., Teltayev B.B., Yensebayeva G.M., Kutimov K.S. (2018) Computer modeling of creep for hereditary materials by abel's kernel // News of the Academy of Sciences of the Republic of Kazakhstan. Series of geology and technical sciences. 2018. Vol. 6, N 432. P. 66-76. ISSN 2518-170X (Online), ISSN 2224-5278 (Print). https://doi.org/10.32014/2018.2518-170X.36

[20] Semerak M., Pozdeev S., Yakovchuk R., Nekora O., Sviatkevych O. (2018) Mathematical modeling of thermal fire effect on tanks with oil products. MATEC Web Conf., 247. 00040 DOI: https://doi.org/10.1051/matecconf/201824700040