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SIMULATION OF HUMAN EVACUATION IN CASE OF FIRE USING PATHFINDER SOFTWARE

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Abstract. This research analyses scientific publications that highlight the problems of evacuation of people during emergencies and the latest methods, techniques and strategies. It is determined that the PATHFINDER software complex gives a more accurate calculation compared to the simplified analytical model. The PATHFINDER software complex allows to simulate evacuation in various buildings and areas. Moreover it gives a wider range of possibilities, such as: simulation of evacuation of people with disabilities; ability to set and adjust the speed of agents in different sections of the escape route; the presence of a function that regulates the onset of movement of agents in a given behaviour.

In this work the computer simulation of the actual time of evacuation of people from the integral property complex of industrial and household facilities was carried out. The duration of the evacuation of people from the rooms of buildings and structures bases on the model of the movement of people to the exit in one of the following ways: based on a simplified analytical model of human flow; based on a mathematical model of the individual-flowing movement of people from a building or structure; based on a simulation-stochastic model of human flows.

These calculations were performed in accordance with the recommendations and instructions using the PATHFINDER software for the two most likely fire scenarios. According to the scenario, the fire occurred in the room with the highest fire-hazardous load or in the room with the smallest volume: scenario 1 - fire occurs in the hot shop; scenario 2 - a fire occurs in the administrative room.

The software provides an opportunity to quickly calculate various ways of evacuating people from the rooms. The use of PATHFINDER software gives more accurate results than the calculation given in regulatory document, due to the greater detalization of the evacuation calculation, and also helps to avoid possible errors and reduce calculation errors.

Keywords: fire, evacuation time, combustion products, modeling, PATHFINDER.

МОДЕЛЮВАННЯ ЕВАКУАЦІЇ ЛЮДЕЙ ПРИ ПОЖЕЖІ ЗА ДОПОМОГОЮ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ PATHFINDER

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Анотація. У цьому дослідженні проводиться аналіз наукових публікацій, які висвітлюють проблемні питання евакуації людей під час надзвичайних ситуацій та новітні методи та стратегії, що спрямовані на забезпечення безпеки. Авторами визначено, що програмний комплекс PATHFINDER дає більш точний розрахунок порівняно зі спрощеною аналітичною моделлю. Програмний комплекс PATHFINDER дозволяє імітувати евакуацію в різних будівлях і зонах. Крім того, це дає більш широкий спектр можливостей, таких як: імітація евакуації людей з обмеженими можливостями; можливість встановлювати та регулювати швидкість агентів на різних ділянках шляху евакуації; наявність функції, яка регулює початок руху агентів у певній поведінці.

В даній роботі проведено комп'ютерне моделювання фактичного часу евакуації людей з цілісного майнового комплексу промислових і побутових об'єктів. Тривалість евакуації людей визначається на основі моделювання руху людей до виходу назовні одним з наступних

способів: за спрощеною аналітичною моделлю руху людського потоку; за математичною моделлю індивідуально-потокового руху людей з будівлі чи споруди; за імітаційно-стохастичною моделлю руху людських потоків.

Наведені розрахунки були виконані відповідно до рекомендацій та інструкцій з використанням програмного забезпечення PATHFINDER для двох найбільш імовірних сценаріїв пожежі. За сценарієм пожежа виникла в приміщенні з найбільшим пожежонебезпечним навантаженням або в приміщенні з найменшим об'ємом: сценарій 1 – пожежа виникає в гарячому цеху; сценарій 2 – пожежа виникає в адміністративному приміщенні.

Програмний комплекс PATHFINDER дає можливість швидко розраховувати різні способи евакуації людей з приміщень. Результати розрахунків є точнішими ніж за ДСТУ 8828:2019, завдяки більшій деталізації розрахунку евакуації, а також дозволяє уникнути можливих помилок та зменшити похибки розрахунків.

Ключові слова: пожежа, час евакуації, продукти горіння, моделювання, PATHFINDER.

1 INTRODUCTION

Every day in Ukraine, on average, occur 277 fires, material damage from which amounts to 34 million 445 thousand (UAH). Every day, as a result of fires, 4 people are killed or get injured, 77 buildings (structures) and 14 pieces of technical equipment are destroyed or damaged by fire. Direct losses from one fire are from 26 thousand (UAH) [1].

According to statistics, the largest proportion of fire deaths is caused by exposure of fire hazards. An important component of saving people's lives is to ensure the correct and timely evacuation from the rooms affected by fire [1].

It is a global practice to use for evacuation calculations not only regulatory documents, but also computer softwares, such as PATHFINDER. It is used for simulation of evacuation in emergency situations with consideration of the possibility of rescuing people.

Among the advantages of the software is the immediacy of calculations, the ability to change the parameters at any time and get the result immediately.

In recent years, there has been an increase in cases of unprofessional calculation of evacuation time by incompetent organisations. As a result, it can lead to death or injury of people in case of realisation of emergency scenarios. The professional calculation of evacuation time forms an appropriate fire safety action plan.

Thus, a relevant scientific and technical task is to improve the calculation methodology using the PATHFINDER software - to model human behaviour in various fire scenarios and calculate evacuation times. This will help to minimise the number of victims of fire or avoid them completely.

2 ANALYSIS OF LITERARY DATA AND PROBLEM STATEMENT

It is noted in [2] that estimating evacuation time is a non-trivial problem due to the interaction between thousands of individual agents, which generates various collective phenomena such as bottlenecks, interrupted flow, and stop-and-go waves. However, it would be advisable to use specialised software such as PATHFINDER, which allows modelling and analysing evacuation processes in complex spatial environments such as buildings and structures.

In [3], the purpose of the study is to emphasise the importance of safety in crowded spaces, such as airports, railway stations, amusement parks, etc. during hours of maximum concentration of people or during large-scale events. The paper reviews the complexity of the evacuation process and sets a task of developing new methods and tools aimed at improving safe evacuation strategies. Particular attention is paid to understanding the dynamics of evacuation, solving the complexity of decision-making during evacuation and using hierarchical models and visual observations to predict people's movements and optimise safe exit routes. However, the PATHFINDER features, that allow to calculate the behaviour of people, which in the program is the set of actions that the agent performs, are not used.

In [4], recognising human behaviour and monitoring real-world environments is a challenging research task. Time series analysis methods, including hidden Markov models, have been used to solve such problems. However in many complex cases they are not effective, because some types of behaviour are much more difficult to model. This is the case, in particular, when there is a lack of raw data. It is advisable to use stochastic models of human behaviour, which are represented by a mathematical model in PATHFINDER.

In [5], it is noted that it is advisable to combine building information modelling technology with geographic information system technology to build a three-dimensional spatial scene of evacuation in case of a fire in a building. It is possible to use a graphical interface to set a graphical data, as well as 2D and 3D visualisation tools. This approach

allows for a quantitative analysis of qualitative indicators related to evacuation and provides an effective visualisation of emergency situations management. The PATHFINDER software allows to use a graphical interface to meet the design and visualisation objectives of the evacuation process.

In [6], the modelling of fire development and the dynamics of people's movement during emergency evacuation is considered. There are three different ways to model fire development: two-zone fire models; computational fluid dynamics (CFD) and stochastic models. PATHFINDER supports two simulation modes. In control mode, agents move independently towards their goal, avoiding other passengers and obstacles. The flow rate through the doors is not defined, but is the result of the interaction of the occupants with each other and with the boundaries of the rooms.

Paper [7] analyses human behaviour in case of a fire in buildings using computer modelling of evacuation. Unpredictable human behaviour in critical situations is at the core of all problems related to the fire safety of buildings, regardless of their purpose. The PATHFINDER software makes it possible to simulate evacuation and program certain agent behaviour, which allows to make such calculations.

In [8], it is proposed to simulate evacuation in emergency situations using a program that contains a graphical interface for creating models and a module for viewing animated three-dimensional results, simulating the rescue of non-mobile groups of people, contours of the density of human flow and a grid for simulating movement.

In [9], the calculation of evacuation was carried out according to the two most likely fire scenarios. When selecting a fire scenario, the following options were assumed: a fire occurs in a room with the highest fire hazardous load or in a room with the smallest volume.

One of the main factors in ensuring the safety of people's lives is the correct calculation of the evacuation of people from the rooms. According to the analysis of fire statistics, the majority of people who die in a fire are those who have been poisoned by toxic combustion products.

The analysis of the publications has shown that the vast majority of works related to evacuation investigate patterns of human behaviour in emergency situations.

3 MATERIALS AND METHODS

The calculation of estimated duration of the evacuation of people from the rooms of buildings and structures bases on the model of the movement of people to the exit in one of the following ways:

- based on a simplified analytical model of human flow;
- based on a mathematical model of the individual-flowing movement of people from a building or structure;
- based on a simulation-stochastic model of human flows.

Calculation of the estimated duration of evacuation of people from the rooms of buildings and structures using a simplified analytical model of the movement of the human flow. The estimated duration of evacuation of people from the rooms of buildings is determined by calculating the duration of movement of one or more human flows through the evacuation exits from the most distant locations of people. During the calculation, the entire path of the human flow is divided into sections (passage, corridor, doorway, flight of stairs, vestibule). The initial sections are the passages between workplaces, equipment, rows of chairs, etc.

Calculation of the estimated time of the evacuation of people from the rooms of buildings and structures using a mathematical model of individual flow. The estimated time of evacuation of people from a building is set by the time the last person leaves it. Before starting the simulation of the evacuation process, the layout of evacuation routes in the

building is set. All evacuation routes are divided into evacuation sections. The length and width of each section of the escape route for buildings under design are taken according to the project, and for constructed buildings - according to the actual value. The length of the path through stairways is measured by the length of the flight of stairs. The path length in a doorway is assumed to be zero. Evacuation areas can be horizontal and inclined (stairs to the bottom, stairs to the top and a ramp). When calculating the dimensions of a person, the area of their horizontal projection is taken as the size of the person. The coordinates of each person are set - the distance from the centre of the projection to the end of the evacuation area where they are located.

Software calculation. PATHFINDER is a computer program that implements an individual model of people's movement during evacuation. The program has a graphical interface for setting the initial data, as well as tools for 2D and 3D visualisation of the results.

PATHFINDER has two modes of motion simulation. In “guided motion” mode, agents use a motion control system to move and interact with each other. This mode attempts to mimic human behaviour as closely as possible.

Agents can be represented by different models. They can be represented by simple shapes, including discs or cylinders. They can also be displayed as mannequin shapes or as human avatars specified in profiles. Settings are available in the “View” menu, “Agents” submenu.

In addition, agents can be painted in different colours through the “View” - “Agent Colour” menu:

- by default. If an individual colour is set for an agent, it is used; otherwise, the colour from the agent profile is used.

- by a motion group. The same colour will be used for all agents of the motion group. The colour of the group is set in the properties panel of the motion group. If the agent is not part of the group, the default colour is used for it.

- by a motion group template. If the agent is part of a motion group that is created using a group template, the agent is coloured according to the template colour for its motion group. Otherwise, the default colour will be used.

- by behaviour. Agents are coloured in accordance with the colour set for their behaviour.

- by profile. Agents are coloured according to the colour specified for their profile.

The main components of evacuation are: rooms bounded by walls; doors connecting rooms on the same level; stairs/ramps connecting rooms on different levels; elevators connecting multiple levels. Rooms can have any polygonal shape and cannot overlap on the same level.

PATHFINDER has two tools for creating new rooms. The “polygonal rooms” tool allows to create complex shape rooms with any number of vertices.

Stairs in PATHFINDER modelled as a single straight stairway and can be created using two tools. One tool creates a staircase between two parallel room boundaries; the other allows to create a staircase with specified parameters, such as a certain number of steps, height difference, etc., at each of the room boundaries.

In PATHFINDER, agents are defined by two groups of parameters: profiles and behaviours.

Profiles define fixed characteristics of agents, such as maximum speed, radius, avatar, and colour. Behaviour: defines a list of actions that the agent performs during the simulation, such as moving to a safe zone, waiting, moving to the exit.

The priority level of the agent. The higher the value, the higher the priority. When moving, agents with a low priority will move out of the way of agents with a higher priority.

The diameter of the cylinder that describes the agent, is its "shoulder width". It is used for path calculation during simulation and collision processing. This value also determines how many agents can be added to a room without overlapping.

Compression ratio. A controlled mode parameter that sets how much agents can shrink when passing each other in narrow corridors. This coefficient must be greater than 0 and less or equal to 1. It makes it possible to take advantage of the elliptical shape of the agents (the ability to turn sideways), as opposed to using exclusively round agents in the calculation.

Behaviours in PATHFINDER are a set of actions that agents perform through the time of simulation. As soon as an agent has completed all its actions, it is removed from the model. Additional actions can make the agent wait, or go to its assignment place, such as a room or a point to an exit.

Thus, to use PATHFINDER, it is necessary to have experience with object modelling software.

According to [10] and many years of experience in calculating the evacuation of people, it is possible to identify the main necessary conditions for the correct formation of an evacuation report:

1. First of all, it is required to study carefully the location of people, employees or visitors in the plans of the rooms of the calculation object.

2. Study the specifics of the factory, institution, organisation, as there are different approaches of calculating evacuation, for example, in school and at manufacture.

3. Mark exits, including emergency exits, on the floor plans to create evacuation routes and flows of people.

4. Check the availability of fire protection systems for early detection and prevention of the spread of fires or other hazardous situations.

5. Calculate the time of evacuation of people to the moment of leaving the building structure.

6. Calculate the fire hazardous components.

7. Obtain the necessary time for the safe evacuation of people.

This is a brief sequence of the process of calculating the required evacuation time.

4 RESEARCH RESULTS

For the calculation, we assume a fire occurrence scenario that realises the worst conditions for evacuating people and/or the highest dynamics of the growth of hazardous fire components.

When choosing a fire scenario, we proceed from the following: a fire occurs in the room with the highest fire hazardous load or in the room with the smallest volume.

Scenario 1 - a fire occurs in a hot shop at +10,900 between the С-Ю/5-6 axis. The area of the room is 113.67 m^2. The hazardous fire components slowly spread throughout the hot shop and to the floor corridor (room 402), the area of the floor corridor is 53.01 m2, the fire develops on a vertical or horizontal surface in the form of a burning rectangle.

Scenario 2 - a fire occurs in an administrative room at the area +10,900-25,600 between the axes Г-А/1-11. The area of the room is 1581 m^2. The fire factors spread throughout the administrative room. The fire evolves on a horizontal or vertical combustion surface in the form of a combustion rectangle.

When determining the number of people to be evacuated from apartments, we use the standards for residential buildings (the area standard is 8 m^2 per person) [10].

The calculation does not take into account technical rooms, bathrooms, kitchens and other rooms where, according to the project documentation, no people are expected to be present and there are no workplaces and compliance with the requirements for the arrangement of escape routes and exits is considered sufficient to ensure safe evacuation from such rooms.

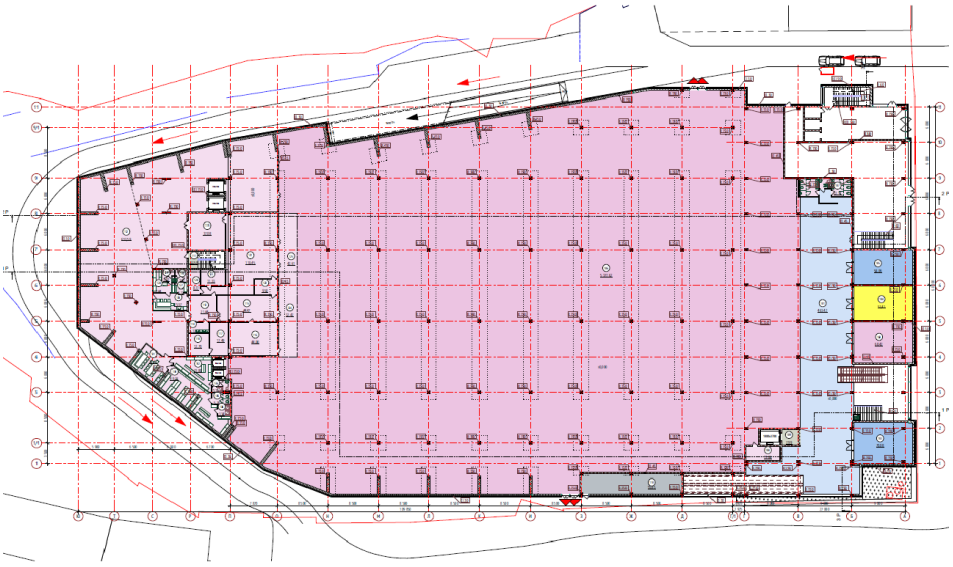

Fig. 1. The plan of the first floor at the point 0,000

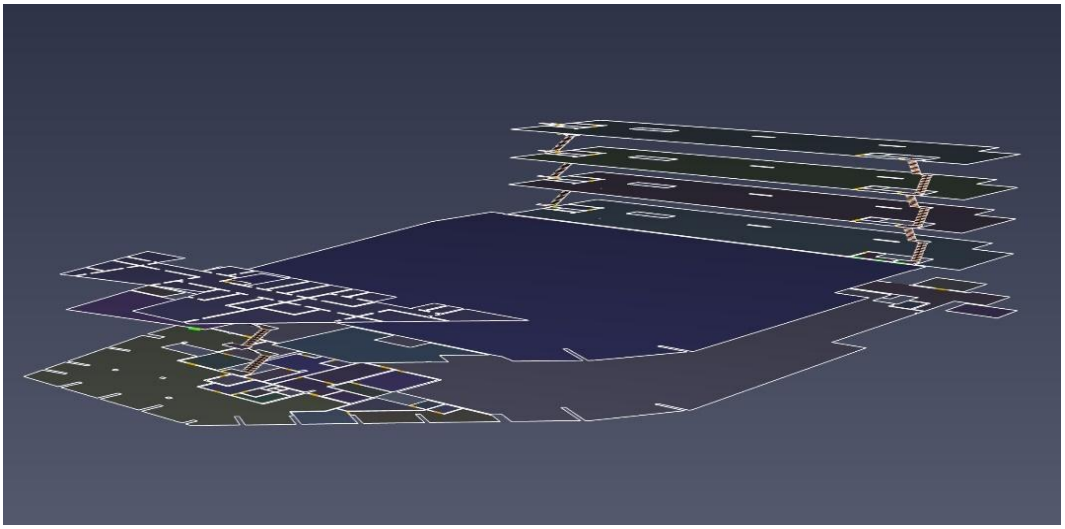

Fig. 2. Simulation of escape routes

For the calculation of the actual evacuation time, a model of the building from which the evacuation will be carried out was created in the PATHFINDER program. Underlays from DWG files were used to build.

A practical calculation of the evacuation time in an integral property complex of industrial and household facilities along Glybochitskaya Street, 44 and Kosogorny Lane, 4 in the district Shevchenkovsky in Kyiv was made. The required evacuation time and the actual evacuation time was determined. These calculations were made in accordance with [10].

For the calculation, we accepted the scenario of a fire causing, in which the worst conditions for the evacuation of people and (or) the highest dynamics of the growth of dangerous fire factors are realised.

The maximum speed of 100 m/min (1.67 m/s) was set. It adjusts automatically for all possible obstacles. In the stream, the speed reached 1.5 m/s, and when overcoming stairs, it reached 1 m/s.

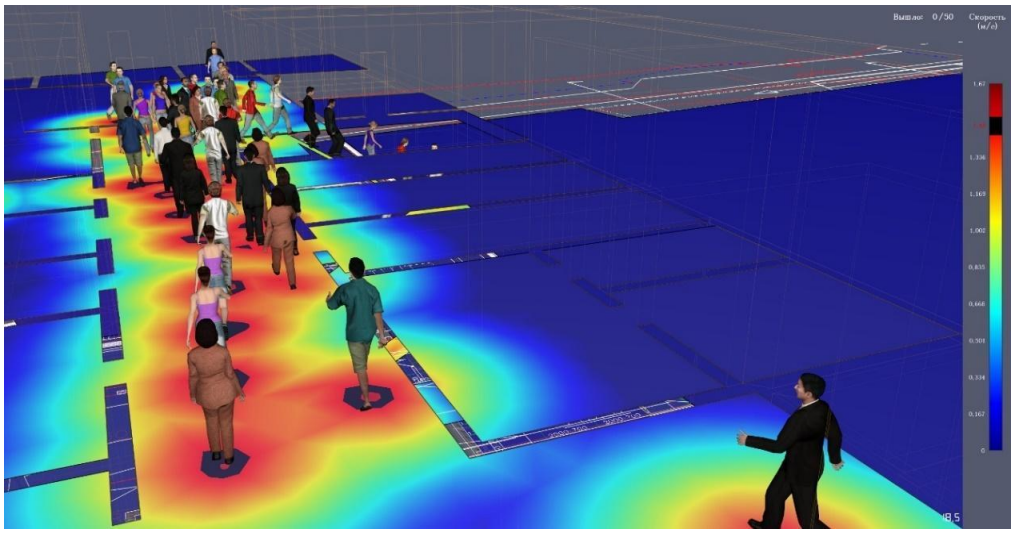

Fig. 3. Agents movement in flow

During evacuation, the human flow has the greatest density near the doorways. As a result of the software calculation, the maximum agent density on area was 3 person per m^2.

Table 1.1.

Calculation results of the required evacuation time

№	Option	Results according to selected scenarios	
		№1	№2
1	Required time for evacuation of people from rooms, sec	198	81

Verifying the fulfilment of the condition of safe evacuation of people (table 1.2).

Table 1.2.

Verifying the conditions for safe evacuation of people

№	Name of the room	Required evacuation time, sec	Evacuation start time, sec	Estimated evacuation time, sec	Verifying conclusion
Administrative building					
1	5th floor	198	20	75	Performed
Technological building					
2	3rd floor	81	20	54	Performed

The two most likely fire scenarios were calculated. When choosing a fire occurring scenario, we proceeded from the following: a fire occurs in a room with the highest fire-hazardous load or in a room with the smallest volume:

- scenario 1 – fire occurs in the hot shop;
- scenario 2 – fire occurs in the administrative room.

The following results were obtained. For Scenario 1, the estimated evacuation time is 54 sec. For Scenario 2, the estimated evacuation time is 75 sec. The actual evacuation time from the third floor of the office building is 120 sec.

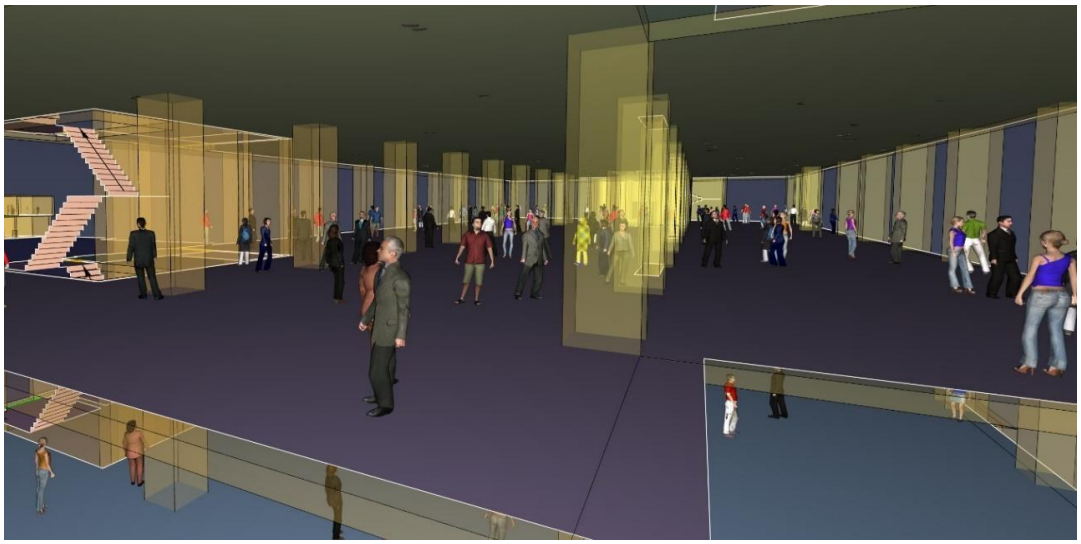

Fig 3. Agents simulation. Scenario 2 “Office building”

A computer simulation of the actual evacuation time was carried out. These calculations were made in accordance with the recommendations and user guides for the PATHFINDER software package. Scenarios:

- scenario 1 – fire occurs in the hot shop;
- scenario 2 – a fire occurs in the administrative room.

The actual evacuation time for the first scenario was 73 sec, and for the second scenario 120 sec.

5 CONCLUSIONS

Based on the results of the studies, the following conclusions were made.

1. Meeting the requirements of regulatory documents to ensure the safe evacuation of people from the buildings during an emergency situation will help minimise the number or even avoid victims that may be the result of a fire.

One of the main factors in ensuring the safety of people's lives is a correctly made calculation of the evacuation of people from the buildings. Since, according to the analysis of statistical data on fires, the main number of those killed in the fire are people who were poisoned by toxic combustion products. Therefore, it is important to evacuate before the onset of extreme fire conditions.

Scientific publications, that investigate problems of evacuation during different emergency situations and new methods, techniques and strategies, were analysed.

2. Computer simulation on the actual time of evacuation of people from the integral property complex of industrial and household facilities on the street Glybochitskaya, 44 and prov. Kosogorny, 4 in the Shevchenko district of Kyiv was carried out. These calculations are made in accordance with the recommendations and instructions for users of the PATHFINDER software.

The calculation was made for the two most likely fire occurring scenarios. Scenarios:

- scenario 1 – fire occurs in the hot shop;
- scenario 2 – a fire occurs in the administrative room.

The actual evacuation time for the first scenario was 73 sec, and for the second scenario 120 sec.

A practical calculation of the evacuation time in an integral property complex of industrial and household facilities along Glybochitskaya Street, 44 and Kosogorny Lane, 4 in

the district Shevchenkovsky in Kyiv was made. The required evacuation time and the actual evacuation time was determined. These calculations were made in accordance with [10].

The two most likely fire scenarios were calculated. When choosing a fire occurring scenario, we proceeded from the following: a fire occurs in a room with the highest fire-hazardous load or in a room with the smallest volume:

- scenario 1 – fire occurs in the hot shop;
- scenario 2 – fire occurs in the administrative room.

The following results were obtained. For Scenario 1, the estimated evacuation time is 54 sec. For Scenario 2, the estimated evacuation time is 75 sec.

Using the PATHFINDER software complex allows to simulate evacuation in various buildings and rooms with the possibility of taking into account such factors as: simulation of evacuation of people with disabilities; ability to set and adjust the speed of agents in different sections of the escape route; the presence of a function that regulates the onset of movement of agents in a given behaviour.

Thus, the use of PATHFINDER software gives more accurate results than the calculation given in regulatory document [10], due to the greater detalization of the evacuation calculation, and also helps to avoid possible errors and reduce calculation errors.

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