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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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ENHANCING THE SAFETY OF EVACUATION OF VISITORS OF SHOPPING AND ENTERTAINMENT CENTRES

Abstract. The paper is devoted to the study of the peculiarities of evacuation of children from entertainment centers and recommendations for improving the safety of visitors to shopping malls based on the results of mathematical modeling of fire development and evacuation processes. To solve the problems set in the work, the FDS software package was used. The FDS mathematical model is based on the use of differential equations in partial derivatives, describing the spatial and temporal distribution of temperature and velocity of the gaseous medium in the room, concentrations of gaseous components (oxygen, combustion products, etc.), pressures and densities. Based on the results of determining the time of negative impact of fire hazards and determining the estimated time of evacuation of people from the children's park located in the mall, it is concluded that spatial planning solutions of the facility allow for evacuating people in case of fire. The scientific novelty of the obtained results is that the time of negative impact of fire hazards and the time of evacuation of people from the children's park of the shopping and entertainment centre was determined for the first time for the conditions of such parameters of a building spatial planning solution. The practical significance of the obtained results is the ability to use the principles and approaches outlined in the article for similar service facilities to determine the required evacuation time, which will increase the safety of visitors and staff in the event of an emergency.

Key words: fire hazards, evacuation, mathematical modelling, FDS.

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САУДА-ОЙЫН-САУЫҚ ОРТАЛЫҚТАРЫНА КЕЛУШІЛЕРДІ ЭВАКУАЦИЯЛАУ ҚАУІПСІЗДІГІН АРТТЫРУ

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ПОВЫШЕНИЕ БЕЗОПАСНОСТИ ЭВАКУАЦИИ ПОСЕТИТЕЛЕЙ ТОРГОВО-РАЗВЛЕКАТЕЛЬНЫХ ЦЕНТРОВ

Аннотация. Статья посвящена изучению особенностей эвакуации детей из развлекательных центров и рекомендациям по повышению безопасности посетителей торговых центров по результатам математического моделирования развития пожара и процессов эвакуации. Для решения поставленных в работе задач использовался программный комплекс FDS. Математическая модель FDS основана на использовании дифференциальных уравнений в частных производных, описывающих пространственное и временное распределение температуры и скорости газовой среды в помещении, концентраций газообразных компонентов (кислорода, продуктов сгорания и др.), давлений и плотности. По результатам определения времени негативного воздействия пожарной опасности и определения расчетного времени эвакуации людей из детского парка, расположенного в ТРЦ, делается вывод, что объемно-планировочные решения объекта позволяют обеспечить эвакуацию людей при пожаре. Научная новизна полученных результатов заключается в том, что впервые определено время негативного воздействия пожарной опасности и время эвакуации людей из детского парка торгово-развлекательного центра для условий таких параметров пространственной конструкции здания, планировочные решения. Практическая значимость полученных результатов заключается в возможности использования изложенных в статье принципов и подходов для объектов аналогичного обслуживания для определения необходимого времени эвакуации, что повысит безопасность посетителей и персонала в случае возникновения чрезвычайной ситуации.

Ключевые слова: пожароопасность, эвакуация, математическое моделирование, FDS.

Introduction. In the recent years, the service industry has been actively developing throughout the world. One of the services provided is children's playrooms (children's

amusement parks) in shopping and entertainment centres. As a result, large groups of unaccompanied children can now be found in not only kindergartens or schools, where their composition is almost homogeneous, represented mainly by children, but also in children's playrooms, where parents leave their children supervised by the staff of the shopping malls.

When analysing scientific sources devoted to the study of the process of evacuation of people from buildings of different functional profiles in emergencies, conspicuous is the fact of poorly explored issues of evacuation of children and the impact of such features on the general evacuation process. The topic mentioned is described in detail in several scientific studies, and only in relation to the evacuation of children from preschools (Tsvirkun, 2020:3), (Shikhalev, 2013:5). There are reasonable concerns regarding the possibility of service staff to establish psychological contact with children in such a short time, to study the mental and behavioural characteristics of an individual child in case of danger, which is one of the main components of successful evacuation of children during a fire. It is not clear how children will behave if there is a real threat of exposure to fire hazards.

Another aspect of the problem is the small amount of research on the parameters of the children evacuation process. In the absence of reliable data on the speed of movement, errors are likely when applying programs to calculate the evacuation parameters. There is no empirical data on the behaviour of children during the forced evacuation in case of fire in the premises of the shopping and entertainment centre. The problem is exacerbated by the fact that children's playrooms (children's amusement parks) are arranged not only on the first floors of shopping and entertainment complexes, but also on the second floors and higher.

Analysis of recent research and publications. Assessing the risk of an adverse event is generally seen as a first step towards quantifying the hazards of facilities, and proposing acceptable risk criteria to develop contingency plans and measures to reduce the potential hazards of business facilities. This article is devoted to the assessment of individual fire risk. It is proposed to assess the individual fire risk following the appropriate scale and the main colour codes and severity levels of risk, where orange (high risk) is added, which makes it possible to more accurately define the boundaries of risk and adapt to generally accepted risk levels. Fire risk forecasting is implemented taking into account the method of calculating fire risks. It is proposed to use graphic editors to visualize the calculation of fire risks for public buildings. Plotting the risks of death from fire in the certain group in the appropriate colours makes it possible to obtain a map of the risk of death from fire, which will allow members of the fire and rescue service to be aware of the possible risks and dangers at a certain facility (Yemelyanenko, 2020:14).

A significant amount of current scientific studies is devoted to the modelling of evacuation processes. Different approaches can be used to model a person's behaviour during a fire in order to carry out evacuation. One study provides a critical overview of the most commonly used modelling methods to represent the evacuation process during fire (Ronchi, 2020:8). There are studies that have developed a simplified simulation

model to calculate the evacuation time on each floor of a building, taking into account a building with different types of accommodation on different floors (e.g. office building, residential building, commercial building, etc.) and different aggregation factors that can be caused by a different configuration of stair doors on each floor. (Sano, 2018:14). In (Kostenko, 2021:9), the expediency of using FDS (Fire Dynamic Simulator) software suite to model the dynamics of fire hazards is shown.

The problem of children evacuation includes the small number of studies to investigate the parameters of the children evacuation process. In the absence of reliable data on the speed of movement, errors are likely to occur when applying software to calculate the evacuation parameters. There is no empirical data on the behaviour of children during the forced evacuation in case of fire in the mall facilities. Therefore, it is impossible to predict exactly how an organized group of children will affect the overall evacuation process.

Some foreign studies (Larusdottir, 2014:1) focus on the specifics of evacuating children. These include:

children are very dependent on adults as for the beginning of the evacuation and as for following the evacuation routes;

the speed of evacuation of children differs significantly from the speed of evacuation of adults;

at the beginning of the evacuation, the method of alerting is of great importance; thus, the most effective method is the 'alarm', which is accompanied by voice instructions;

during evacuation, children are more inclined to focus on large crowds of people (children) than on adults who are engaged in their evacuation;

children use railings on the stairs only in the case of self-evacuation, if there is an adult nearby, they almost never use railings;

drills have a positive effect on the time of evacuation from the room.

The Illinois Building Regulations (USA) (Building Code 2018 of Illinois, 2018:1) define the requirements for children's entertainment centres (for structures higher than 3 meters and with an area of more than 14 sq.m). All structures at the children's playgrounds (centres) shall be made of non-combustible materials; if the structures contain combustible materials, they shall meet the requirements for wood, plastic, foam, aluminium, textiles. Also, some requirements are defined for flooring materials. Fire-fighting equipment, which is used to equip playgrounds, shall be not inferior to the equipment of the adjacent premises located on the same floor. The structures of the playgrounds shall be located at a distance of at least 1.5 m from walls, structural elements and potential exits. The structures of the playgrounds shall be spaced for at least 6 meters. The structures of the playgrounds shall have an area of not more than 28 sq.m, unless otherwise permitted by special fire investigation.

Setting the objectives of the article. The objective of the article is to increase the safety of visitors in the premises of the Children's Planet Park, located in the mall, based on the results of mathematical modelling of fire spread and evacuation processes.

To achieve this objective, the following tasks need to be solved:

to analyse the ways of evacuation within the framework of spatial planning solutions of the mall facility;

to calculate the necessary and actual time of visitors' evacuation;

to determine the features of evacuation from children's entertainment centres located in the mall.

Study methods. The main modern approaches to the study of safe evacuation are computer modelling using computational fluid dynamics (CFD). FDS software suite was used to determine the fire hazards (McGrattan, 2000:1). FDS numerically solves the Navier-Stokes equation for low-velocity temperature-dependent flows, with special emphasis on the spread of smoke and heat transfer during a fire. The FDS mathematical model is based on the use of differential equations in partial derivatives, describing the spatial and temporal distribution of temperature and velocity of the gaseous medium in the room, concentrations of gaseous components (oxygen, combustion products, etc.), pressures and densities.

Presentation of the study basic material. Ensuring the evacuation of people consists in spatial planning and design solutions, which allow completing the evacuation from the facility before the onset of the maximum allowable values of fire hazards to a man.

When analysing the drawings of the Children's Planet amusement park, located in the mall, it was decided to calculate the time of evacuation and the occurrence of fire hazards following two scenarios.

Scenario No. 1. The centre of the fire is located in the switchboard near the evacuation exit, the trampoline and the area of the iXbox machines, and there is a maze nearby. Thus, a fire is modelled in the place of probable presence of the largest number of children. According to the scenario, the trampoline is completely filled, with 150 children located there. The fire was caused by a short circuit. The time of occurrence of fire hazards and the time of evacuation of people by evacuation routes are calculated.

Scenario No. 2. The initial conditions of scenario No. 2 are the same as for scenario No. 1, namely the centre of the fire is located in the switchboard near the evacuation exit, trampoline and the area of iXbox machine, and there is a maze nearby. Scenario No. 2 differs in taking into account the probability that visitors (according to statistical studies) are evacuated the way they entered a particular room.

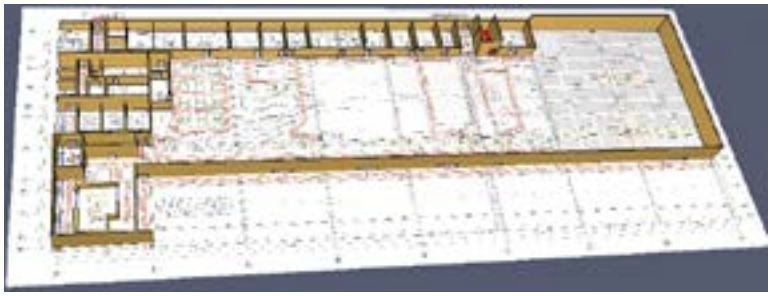

Figure 1 - Room model for simulation of the dynamics of fire hazards

Determination of the estimated time of evacuation of people from the rooms is carried out using a simplified analytical model of human traffic flow (State standard of Ukraine 8828, 2019:5).

FDS software suite was chosen to model the dynamics of fire hazards. The choice of the software suite is due to the complex geometry of the ceiling (roof) of the facility, which makes it impossible to use simpler methods of calculating fire hazards.

When obtaining graphical and analytical results of the calculation of the fields of fire hazards, the locations of the calculation points were taken as the places of the longest presence of people according to the relevant scenario, in the immediate vicinity of the evacuation exits.

Maximum permissible values for each of the fire hazards (McGrattan, 2000:1):

- by elevated temperature: 70°C;
- by loss of visibility: 20 m;
- by low oxygen content: 0.226 kg/cu.m;
- by CO_2 concentration: 0.11 kg/cu.m;
- by CO concentration: $1.16 \cdot 10^{-3}$ kg/cu.m;
- by HCl concentration: $2.3 \cdot 10^{-5}$ kg/cu.m.

Figure 2 - Schematic of the room and location of sensors measuring indicators of fire hazards

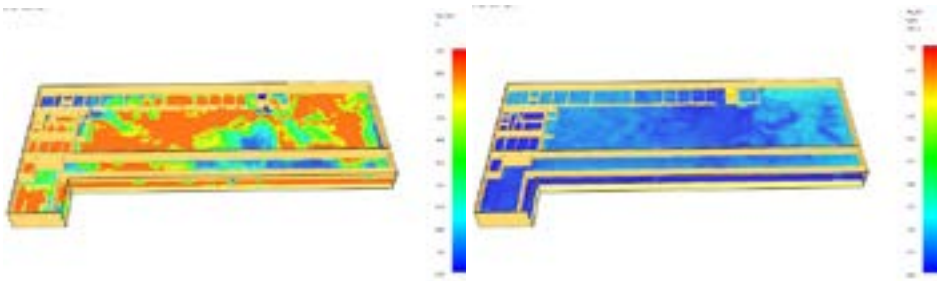

Figure 3 - Distribution of visibility fields and HCl concentrations in the room

The fire seats were chosen in such a way as to either block one of the evacuation exits or create difficult conditions for evacuation. Thus, the fire develops in the worst-case scenario; we assume that the automatic fire extinguishing system, which is installed in the shopping and entertainment complex, failed. In these conditions, the time of

occurrence of fire hazards in 23 key locations of the children's amusement park is calculated (required evacuation time). The estimated evacuation time, which depends on the spatial planning solutions, shall be less than the required evacuation time.

Fire load characteristics:

- lower heat of combustion 30.7 MJ/kg;
- linear velocity of flame propagation 0.0071 m/s
- specific heat of 749 kJ/sq.m
- specific mass burnout rate 0.024 kg/sq.m*s
- smoke-generating capacity 521 Np*sq.m/kg
- oxygen consumption 2.19 kg/kg
- carbon dioxide emission 0.65 kg/kg
- carbon monoxide emission 0.13 kg/kg
- hydrogen chloride emission 0.02 kg/kg

Table 1. Time to reach the fire hazard

Sensors	Time to reach the fire hazard*						
	CO content	CO_2 content	HCl content	Underestimated O_2 content	Elevated temperature	Loss of visibility	Heat flow
Sensor 1	489	-	424	-	499	290	-
Sensor 2	-	-	434	-	-	376	-
Sensor 3	345	-	203	394	394	170	-
Sensor 4	338	-	158	361	361	139	-
Sensor 5	403	-	171	398	378	129	-
Sensor 6	417	-	192	412	378	165	-
Sensor 7	-	-	500	-	-	480	-
Sensor 8	437	-	252	430	408	203	-
Sensor 9	428	-	205	423	390	181	-
Sensor 10	462	-	300	-	471	295	-
Sensor 11	-	-	392	-	-	295	-
Sensor 12	-	-	378	-	489	311	-
Sensor 13	-	-	360	-	-	298	-
Sensor 14	-	-	320	-	-	304	-
Sensor 15	-	-	451	-	-	439	-
Sensor 16	-	-	478	-	-	468	-
Sensor 17	-	-	484	-	-	453	-
Sensor 18	-	-	482	-	-	421	-
Sensor 19**	-	-	-	-	-	-	-
Sensor 20	-	-	270	-	-	228	-
Sensor 21	-	-	405	-	-	338	-
Sensor 22	-	-	394	-	-	388	-
Sensor 23	-	-	363	-	-	288	-

* time (in seconds) of the occurrence of a specific dangerous factor of fire from the beginning of the fire is indicated

** simulation of the spread of fire hazards for 500 seconds was carried out; during this period of time critical values were not reached at the location of sensor No. 19

Figure 4 - Schematic of evacuation routes

Table 2. Time of crossing reference points (scenario No. 1)

Route	Section number	Estimated time (seconds)*	Required time (seconds)	Sensor	Numbers of sections that are taken into account to determine the estimated time of evacuation
Route No. 1	26	116.4	165	6	11, 14, 18, 22, 25, 26
Route No. 1	29	195.6	480	7	11, 14, 18, 22, 25, 26, 27, 28, 29
Route No. 2	55	114.6	181	9	40, 43, 46, 50, 52, 55
Route No. 2	60	172.2	295	10	40, 43, 46, 50, 52, 55, 56, 57, 58, 59, 60
Route No. 3	97	276	298	13	72, 73, 75, 76, 85, 86, 87, 97
Route No. 4	146	176.4	304	14	111, 112, 113, 123, 127, 132, 135, 136, 137, 140, 146
Route No. 5	179	378.6**	439	15	160, 163, 164, 165, 168, 169, 170, 178, 179
Route No. 6	237	190.2	228	20	217, 218, 220, 221, 228, 237
Route No. 7	269	205.8	468	16	194, 209, 250, 252, 253, 254, 267, 268
Route No. 8	309	118.2	421	18	280, 284, 285, 286, 309
Route No. 9	333	114.6	180	-	320, 321, 323, 327, 333

* taken into account time of the beginning of the evacuation +0.5 minutes, according to [9]

** 5 minutes have been added to the estimated time to evacuate children from the maze

Table 3. Time of crossing reference points (scenario No. 2)

Route	Section number	Estimated time (seconds)*	Required time (seconds)	Sensor	Numbers of sections that are taken into account to determine the estimated time of evacuation
Route No. 6	240	228.6	(intermediate section)	-	217, 218, 220, 221, 228, 240
Route No. 8	309	379.2	421	18	217, 218, 220, 221, 228, 240, 280, 284, 285, 286, 309
Route No. 9	333	114.6	180		320, 321, 323, 327, 333

* taken into account time of the beginning of the evacuation +0.5 minutes, according to [9]

According to the results obtained, the safe evacuation from the premises of the mall is possible.

Discussion and conclusion. Based on the results of determining the time of negative impact of fire hazards and determining the estimated time of evacuation of people from the children's park located in the mall, it is concluded that spatial planning solutions of

the facility allow for evacuating people in case of fire. However, it should be noted that children are more prone to panic than adults are, and in case of fire, they tend to hide instead of leaving the room. Therefore, the staff of the institution must flawlessly control the number of children on playground attractions such as trampolines and mazes, and establish clear instructions on how to act in case of fire.

The scientific novelty of the obtained results is that the time of negative impact of fire hazards and the time of evacuation of people from the children's park of the shopping and entertainment centre was determined for the first time for the conditions of such parameters of a building spatial planning solutions.

Due to the lack of regulatory framework in Ukraine that regulates the requirements for children's playgrounds located in large shopping centres, the study data may be the basis for developing a concept for child safety in such facilities given the risk of an emergency.

We suggest the following provisions of the concept to be taken into account:

Drills interval. The playground staff shall participate in regular drills, as noted, e.g., in (MSDH, 2022:2), which require monthly training of the staff to evacuate children from the playgrounds in the event of a fire or other emergency.

Arrangement of evacuation exits. Emergency exit doors shall be fitted with means of exit only in the event of fire, and must not be opened by children during normal operation.

Alerting the parents. We suggest to develop a concept of alerting the parents about an emergency situation, e.g., with the help of text messages specifying the location of children after evacuation.

Spatial planning solutions. The structures of children playgrounds shall provide for the possibility of rapid unimpeded access of adults to children. Such a measure will save those children who are scared and do not try to leave the room on their own.

Information materials, where in the form of games and taking into account different age groups of children, information will be provided on the sequence of actions in case of an emergency.

The practical significance of the obtained results is the ability to use the principles and approaches outlined in the article for similar service facilities to determine the required evacuation time, which will increase the safety of visitors and staff in the event of an emergency.

In our opinion, the behaviour of the staff of shopping malls in case of fire needs to be studied further. If a series of experiments is successfully carried out in several shopping and entertainment complexes, preferably in different regions of the country and at different times of the year, it will be possible to compare the results of field studies with the results obtained by computer simulation, to make necessary calculations and to draw conclusions.

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