

FIELD STUDIES ON THE EFFICIENCY OF FIRE EVACUATION PROCEDURES IN BUILDINGS

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Purpose: The purpose of the study is to identify the human movement characteristics during fire evacuation in complex and unfamiliar topological conditions of evacuation routes.

Design/methodology/approach: The study uses the methods of observation, recording, and measurement of the evacuation process of people from a building. A survey method was used to identify the main motivational factors to make a decision under conditions of limited time and insufficient information. Analytical calculations were conducted to determine the normative evacuation parameters and predict conditions along evacuation routes in case of smoke resulting from fire.

Findings: The patterns in decision-making during evacuation from buildings in unfamiliar topological conditions, influenced by psychological factors, were found. They include the impact of light along the evacuation route, possible misinterpretation of information signs that resemble fire evacuation signs, and a high probability of indistinguishable evacuation signs when the background color matches the color of the sign's informational elements under certain lighting conditions.

Research limitations/implications: During field studies, it was not possible to fully simulate stressful conditions of evacuation due to some ethical considerations.

Practical implications: The findings of the research provide legislators and fire safety policy makers with evidence-based approaches, which they can use to improve the normative requirements for evacuation routes in fire emergencies in buildings of various types.

Social implications: Psychological patterns of people's behavior during evacuation will help reduce the risk of injury in fires due to the improved requirements for evacuation routes.

Originality/value: The research has revealed new psychological traits of human behavior in complex topological conditions along evacuation routes in buildings on fire. They arise due to the factors that were not previously considered in the design of evacuation routes, including unfamiliar (or less familiar) environments, varying light levels in different sections of evacuation paths, and information signs resembling standard fire safety ones.

Keywords: evacuation, building, fire, evacuation signs, limited information.

Category of the paper: Viewpoint.

1. Introduction

The evacuation of occupants from buildings during fire emergencies is a key priority of fire safety measures in the context of emergency response. In Ukraine, according to general regulatory requirements for evacuation, as outlined in the State Building Codes (DBN V.1.1-7:2016), it is necessary to ensure timely, unobstructed, and safe conditions for evacuation, which is considered to be evacuation efficiency.

In Ukraine, due to ongoing military actions, fires occur almost daily, particularly in cities near the frontline. Thus, the issue of ensuring safe and efficient evacuation from buildings is highly relevant.

The issue of efficient evacuation of people from buildings has been the subject of extensive scientific research both in Ukraine and in countries of the European Union and the Americas (see e.g., Goatin et al., 2009; Pan et al., 2020; Gerges al., 2021; Ahn et al., 2022; Fu et al., 2024; Tsvirkun et al., 2015; Maiboroda et al., 2023; Kovalishyn et al., 2022; Dotsenko, 2023). These studies examine the influence of various factors on the evacuation process, such as the presence of different mobility groups in evacuation flows, the impact of building height, and obstacles on evacuation parameters, etc.

This work is the result of joint research carried out by the scholars from Lodz University of Technology and REI 'Prydniprovsk State Academy of Civil Engineering and Architecture' of the Ukrainian State University of Science and Technologies. The study of the evacuation process was conducted according to the requirements of Ukrainian fire safety standards and regulations (State Standard of Ukraine DSTU ISO 23601:2019; State Standard of Ukraine DSTU 8828:2019; State Standard of Ukraine DSTU EN ISO 7010:2019).

2. Methods

Global practice shows that even when evacuation routes are properly arranged in buildings (especially intended for public use), people may get trapped or injured on these routes. This can occur due to violations of evacuation route design standards as well as psychological factors, such as human behavior patterns and misunderstanding of evacuation signs under stress.

To study the specific features of this process in detail, we conducted time-motion measurements to determine the actual evacuation time of people in case of fire from a five-storey academic building in various topological conditions of evacuation routes. The building has a complex layout due to multiple sections and wings, with corridor length up to 80 meters (Figure 1).

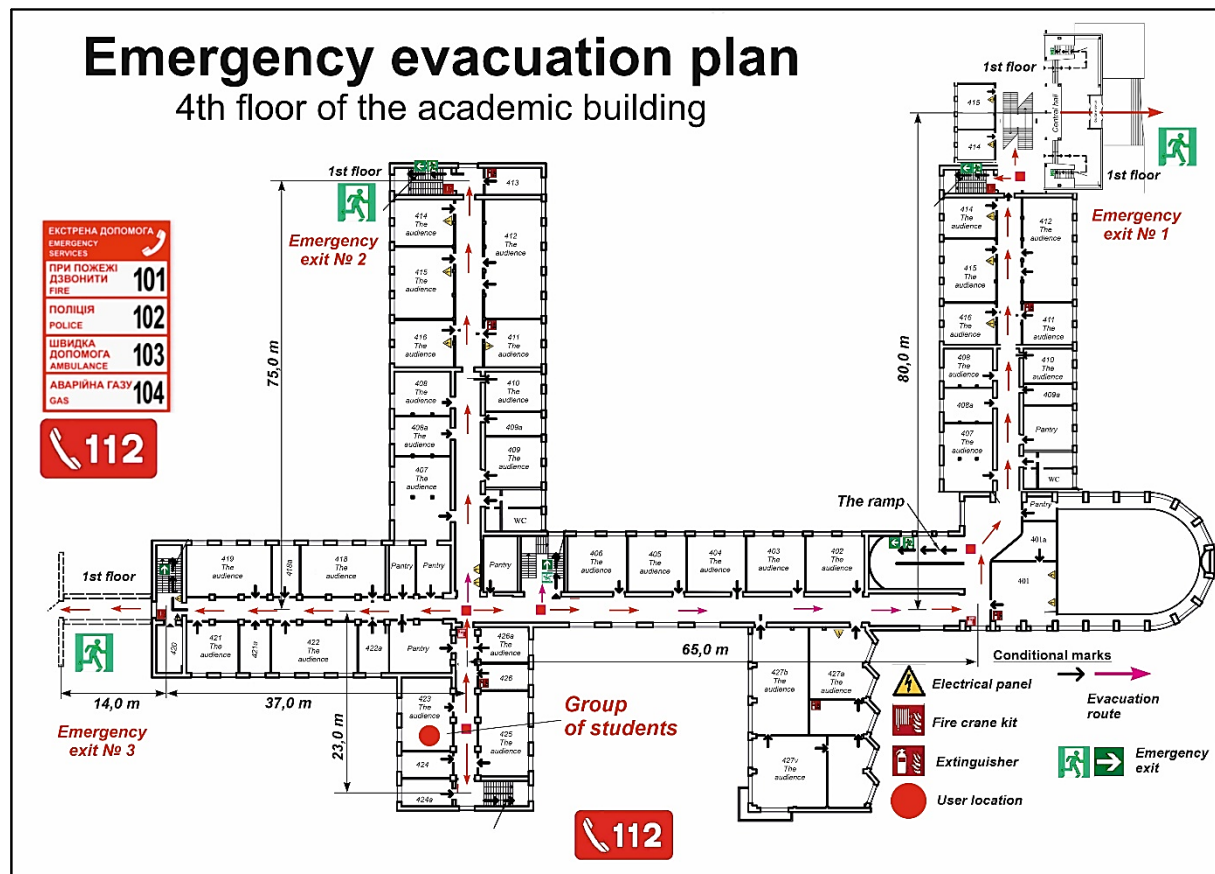


Figure 1. General layout of the experimental section of the evacuation route.

Source: Own research.

The study examined both psychological aspects of human behavior during evacuation and the ability of people to navigate unfamiliar buildings using evacuation signs, as well as technical factors related to the placement and visual perception of these signs.

Five groups of people participated in the study. The test groups consisted of young individuals (students) aged 18-25. They were divided into two categories: two groups were familiar (fully or partially) with the building and the location of the main evacuation exits, as they studied in the classrooms of this building; and three groups were students from other universities who were unfamiliar with the building and visited it for the first time. The students who were partially familiar with the building layout attended the university only during exam sessions (once a year) and no more than 3-4 times per month. The reason is the COVID-19 pandemic and the ongoing war since 2022, when all classes were conducted online.

During the research, the evacuation routes in the building were marked according to the minimum regulatory requirements of Ukrainian standards (State Standard of Ukraine EN ISO 7010:2019) (Figure 2).



Figure 2. Fire evacuation signs according to the evacuation plan.

Source: Own research.

It is not possible to fully simulate a state of stress in an evacuation drill. However, a certain level of psychological tension was felt during the experiment due to the overall threat environment in the city of Dnipro, the limited time for evacuation, and the complicated initial conditions, such as blocked exits that students normally use. The latter conditions were provided only to the groups familiar with the building.

The study used several methods: time-motion measurements, observation of the evacuation process (including video recording), statistical analysis of the measurement results, and participant surveys to assess psychological factors influencing evacuation behavior.

3. Results

During the time-motion measurements, the time when the students left the building was recorded for both the first and the last subgroups, which spontaneously separated in the evacuation process. Table 1 shows measurement results of the evacuation process.

Table 1.
Results of parameter measurements of evacuation process from the academic building

№ group / subgroup	Number of people	Ratio of men to women in the group, %	Number of subgroups	Average movement velocity, m/min	Actual evacuation time, minutes.
People familiar with the building layout					
1	9	45/55	4		
1.1	3			85	12,5
1.2	2			88	7,1
1.3	3			92	4,2
1.4	1			96	3,5
2	10	50/50	3		
	6			92	4,7
	4			95	3,6

Cont. table 1.

People unfamiliar with the building layout					
3	9	80/20	5		
3.1	2			87	2,3
3.2	1			92	5,3
3.3	3			92	6,3
3.4	1			95	9,4
3.5	2			82	12,1
4	12	50/50	2		
4.1	6			90	3,1
4.2	6			92	4,0
5	17	70/30	3		
5.1	10			92	2,5
5.2	3			95	3,2
5.3	4			90	4,1

Source: Own research.

The average movement time for each subgroup was calculated using coordinates obtained from video recordings. In each measurement, the coordinates of two different participants (x_1 and x_2) at a specific moment in time t_n were identified in pairs. Then, the distance between them was calculated using the following formula:

$$a(t_n) = x_1(t_n) - x_2(t_n) \quad (1)$$

For the next moment in time t_{n+1} , the data $x_1(t_{n+1})$, $x_2(t_{n+1})$ were recorded using the same method.

For each time interval between measurements, the average velocity was calculated using the formula:

$$V_{aver} = \frac{1}{2} \cdot \frac{(x_1(t_{n+1}) - x_1(t_n)) + (x_2(t_{n+1}) - x_2(t_n))}{(t_{n+1} - t_n)} \quad (2)$$

As shown in Table 1, the average movement velocity of the groups of people was 5-18% lower than the standard values (State Building Codes DBN V.1.1-7:2016) for conditions with minimum flow density of 0.01 m²/m².

Additionally, the actual evacuation time of people from the building was compared with the normative calculated evacuation time, according to the State Standard of Ukraine, using a simplified analytical model of flow movement (State Standard of Ukraine 8828:2019). The evacuation time was estimated for the farthest evacuation exit. The layout of this evacuation route included 8 horizontal sections and one downward staircase section (Figure 3).

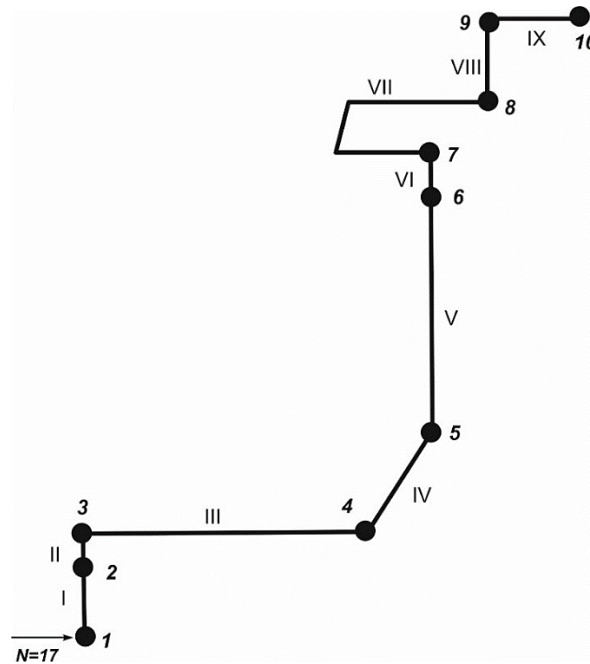


Figure 3. Estimated evacuation scheme of the longest route.

Source: Own research based on design.

Estimated evacuation time of people t_p is the total movement time of people flow in different sections of the route:

$$t_p = t_1 + t_2 + \dots + t_i, \quad (3)$$

where:

t_1 – movement time of people flow on the first (initial) section, min,

$t_2 \dots t_i$ – movement time people flow on the next sections, min.

The movement time of people flow along the route section was calculated using the formula:

$$t_1 = \frac{l_1}{V_1} \quad (4)$$

V_1 – velocity value of people flow depends on flow density D , m/min, as specified in Table A.1 (State Standard of Ukraine 8828:2019).

Density of people flow D on the route section with the length l_i and the width δ_i is calculated according to the following formula:

$$D_i = \frac{N_i f}{l_i \cdot \delta_i} \quad (5)$$

where:

D_i – density of people flow on the evacuation route m^2/m^2 ,

N_i – number of people on the first section,

f – average size of a person's horizontal projection, m^2 , according to State Standard of Ukraine 8828:2019.

Congestion depends on people flow intensity q , m/min, which must not exceed the established maximum values. The calculation results are presented in Table 2.

Table 2.

Calculations of the estimated evacuation time from the building according to the evacuation route presented in Figure 3

№ section	Type of premise	<i>N</i>	<i>b, m</i>	<i>l, m</i>	<i>D, m²/m²</i>	<i>q, m/min.</i>	<i>v, m/min.</i>	<i>t, min.</i>
I	corridor on the 4th floor	17	3,0	6,0	0,12	8,5	79	0,07
II	doors	17	2,5	–	–	8,9	–	–
III	corridor on the 4th floor	17	3,0	65	–	1,0	100	0,65
IV	corridor on the 4th floor	17	5,0	10	–	0,8	100	0,01
V	corridor on the 4th floor	17	3,0	80	–	1,0	100	0,8
VI	doors	17	2,5	–	–	1,3	–	–
VII	downstairs	17	2,0	40	–	2,8	100	0,4
VIII	corridor on the 1th floor	17	6,0	20	–	0,9	100	0,2
IX	lobby on the 1th floor	17	10	20	–	0,5	100	0,2
								Σ 2,3

Source: Own research.

The capacity of the sections (corridors, lobbies, foyers) along the evacuation routes significantly exceeded the calculated values, because a relatively small number of people participated in the experiment. Therefore, the velocity of people flow was not limited by flow density. It depended solely on human speed of perception and interpretation of fire evacuation signs, as well as the choice of a correct route at corridor intersections.

4. Discussion

The results of the calculations and time measurements showed that the actual evacuation time exceeded the estimated time in all cases. The groups familiar with the building exceeded the time of evacuation from 1.3 to 5.1 times, the unfamiliar groups - from 3.1 to 12.2 times. Only in two out of sixteen cases the time coincided.

The analysis of the calculation results and observations showed that the evacuation time was increased due to insufficient informational support in the organization of evacuation routes, especially for individuals who were unfamiliar with the building (e.g., first-time visitors) but not due to a reduced velocity.

In Ukraine, there are no clear regulatory requirements for the height and frequency of evacuation signage. As a result, there are cases where the signs are positioned higher than 3 meters.

Psychological aspects of human behavior and perception of information from evacuation signs and evacuation plans were recorded with the help of two methods: observation of student groups during the experiment and analysis of questionnaire responses from participants. The results revealed some new as well as well-known psychological factors influencing decision-making in the selection and alteration of evacuation routes. Among the well-known factors, it was found that in 100% of cases, people leaving the classroom (the initial evacuation

point) began moving in the same direction which they had entered the building despite of evacuation signs indicating an alternative route.

Among the new factors, we consider the fact that people will likely move towards better-lit parts of the building at corridor intersections (Figure 4).



Figure 4. Corridor entrances: a well-lit area ($E = 257$ lux) and a dimly lit area ($E = 17$ lux).

Source: Own research.

In our case, none of the nine groups chose to move through the dimly lit corridor under other equal conditions and evacuation signs. The actual illumination levels of the corridors were as follows: 17 lux (floor level) in the dimly lit section and 257 lux (floor level) in the well-lit section. Although, according to Ukrainian regulations, emergency corridor lighting may be reduced to 1 lux, we believe that these are not the absolute illuminance values but their ratio which influence the decision-making. Subjectively, it creates the perception that the better-lit area is a safer direction. At night, emergency lighting even at $E = 1$ lux gives a sense of a safe exit in the illuminated corridors compared to dark ones. However, during the day, similar conditions may arise due to the absence of windows in some corridors or partial smoke.

While observing the evacuation process, we have found that it was difficult to understand the evacuation signs, according to the State Standard of Ukraine EN ISO 7010:2019. They are placed on a green background in a darkened corridor, even in conditions when rays of natural light fall perpendicularly on the sign surface (Figure 5).



Figure 5. The sign of emergency exit from different distances - 5, 2.5, and 1.5 meters. The glare is on sign surface in a dark corridor from rays of natural light.

Source: Own research.

At a distance of 3-4 meters the emergency exit pictogram blends with the background due to glare. Smoke in premises can worsen the visibility. To take this factor into account, we performed a visibility assessment of evacuation signs with smoke under specific corridor conditions on the 4th floor, using the methodology developed by American researchers (see Klote et al., 2002).

The analysis considered the material type, mass, and smoke production characteristics of wall claddings and finishes, floor coverings, the size of the room, the sign type (retroreflective), and the combustion type. The calculation was performed using a functional dependency:

$$S = \frac{K}{\alpha_m \cdot m_p} \quad (6)$$

where:

S – visibility, fi (m),

K – proportionality constant (Table 3.3, [14]),

α_m – specific extinction coefficient, ft²/lb (m²/g),

m_p – mass concentration of particulate lb/fi³ (g/m³).

According to the calculation, the minimum recognition distance of the sign is 6 meters in conditions of white smoke, standard ambient lighting, and average visual acuity. However, in reduced lighting, this distance decreases to approximately 1 meter.

While observing people's movements along evacuation routes, instances of misinterpretation of information signs as fire evacuation ones were recorded in two subgroups (Figure 6).



Figure 6. Information sign design resembling the fire evacuation direction sign.

Source: Own research.

Such signs contain similar informational elements (in this case, an arrow), which resulted in the wrong choice of evacuation route. This issue is especially critical for individuals who lack knowledge of basic fire safety principles and standard design of fire evacuation signs.

5. Summary

As a result of the research, patterns in decision-making during evacuation from the building in unfamiliar topological conditions were identified, influenced by psychological factors. These include the impact of light along evacuation routes, potential misinterpretation of information signs resembling fire evacuation ones, and a high probability that evacuation signs cannot be distinguished. It occurs when the background color matches the color of the sign's informational elements in certain lighting conditions.

The study revealed new psychological characteristics of human behavior in complex topological environments during evacuation. They arise from factors that were previously overlooked in the design of evacuation routes. These factors include unfamiliar or poorly known spatial layouts, varying degrees of relative illumination along evacuation routes, and information signs similar to standard fire safety signs.

The practical findings provide legislators and fire safety policy makers with evidence-based approaches to improving the requirements for evacuation routes in buildings of various types. The psychological patterns of human behavior during evacuation can help reduce the risk of injury in fire emergencies by enhancing the regulatory requirements for evacuation routes.

Based on the analysis of relevant literature, the identified behavioral patterns are also applicable within the regulatory framework of the Republic of Poland, as the psychological factors examined in this study have not been addressed in existing European research.

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