Modification of the security system for using vertical transport during the operation of a high-rise building

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Abstract. The article explores the principles of organizing an integrated system of vertical transport to ensure the safe operation of high-rise buildings and the possibility of improving it. The reasons for the violation of the safety of using a tall building and the factors for their prevention and elimination were analyzed. The relevance of the study is justified by the non-zero probability of emergency situations and possible human casualties. On the example of a warning and evacuation control system in the event of a fire, methods of intelligent control of human flows are considered. The aim of the study was the proposal to introduce additional tools to make the vertical transport system safer and faster in the event of any emergency. The objective of the study was to calculate the rationale for these proposals. The calculation results confirm the effectiveness of the proposals, which will lead to a reduction in the time of evacuation, reduction of consequences in the form of stress and injuries for people.

1. Introduction

Currently, high-rise buildings are becoming an integral part of even relatively small cities in terms of population density. They are not only multifunctional real estate that performs social, residential, retail, entertainment and other functions, but also solve the problems of the diversity of the urban environment. According to statistics, the global tendency to increase the number of storeys of buildings every year only increases (Figure 1).

![Figure 1. The increase in the height of the 100 tallest buildings in the world according to CTBUH.](image-url)
Due to the fact that high-rise buildings accommodate a large number of people, during operation there is a need to ensure a safe stay both in regulatory conditions and in extreme situations. A review of regulatory documents and scientific research by various authors shows [1-3] that the user of a high-rise building is exposed to various types of influences from the working environment. In turn, the operational safety of people in high-rise buildings depends on various factors and characteristics, and can also be ensured by special events. The main factors and characteristics include:

- space-planning features of the building and its individual floors;
- constructive solution of supporting and enclosing structures;
- the effectiveness of existing engineering systems;
- availability of security systems and their level of automation;
- quality of operation of building structures and systems;
- awareness of both service personnel and users about the behavior algorithms in case of a dangerous situation.

Based on the analysis of studies in the field of ensuring the quality of operation and safety of high-rise buildings, risk assessment [2, 4-7], an Ishikawa diagram (Figure 2) was compiled to study possible directions for improving the operational safety system of vertical transport.

Figure 2. Diagram of analysis of the root causes of security violations in the use of a high-rise building and the factors of their neutralization.

However, despite the fact that high-rise buildings are a complex technical system equipped with an integrated security system, there is a problem of effective control of the movement of people in the event of an emergency. As a rule, there are users who ignore the first warnings about a dangerous situation, which leads to a critical loss of time. As a result of a stressful situation, panic occurs, a loss of orientation in space occurs. In such a situation, ready-made control algorithms do not work.

As an emergency, consider the occurrence of a fire and the need for safe evacuation of people. Currently, this dangerous situation has been modeled in a large number of works [8-10], fire risk assessment methods [11-13], various systems and technologies for safe evacuation, in particular, a warning and evacuation management system for people in case of fire, have been developed. A lot of research is devoted to the integration of various behavior algorithms depending on the types of data.
systems [14-16]. However, the problem of safe evacuation remains relevant. So, in 1974, a fire in a 25-story building in San Paulo (Brazil) killed 227 people. In 1988, more than 40 people were injured in a fire in the 62-story building of First Interstate Bank (Los Angeles, USA). In 1997, 15 people died in a fire in a 25-story bank in Indonesia. In 2017, 12 people died in a fire in a 24-story residential building in London. Consequently, improving the security system for using tall buildings remains a vital task, which justifies the relevance of this study.

The hypothesis of the study was that one of the causes of the problem in question is the lack of information in the event of an emergency. As a result, the underestimation of physiological and psychological characteristics leads to the fact that the primary actions of both users and staff are aimed at studying the situation, and not at the evacuation itself. To solve the problem under consideration, a modification of the system for ensuring the safety of using vertical transport is proposed based on the strengthening of the role of users in the evacuation process and focused on psychological support in the form of a virtual presence of the person responsible for the evacuation. The main objectives of the study were:

1. Analysis of types of warning systems and people flow control in case of fire.
2. Development of proposals for the modification of the warning system and the management of vertical transport for the possibility of its use in various emergency situations.
3. The calculate justification of the effectiveness of the proposed solutions.

2. Materials and Methods
The object of the study was a warning system and control the flow of people in case of fire (hereinafter the system). The subject of the study was ways to increase the efficiency of the vertical transport system to increase the safety of using high-rise buildings.

The study of the effectiveness of the system is based on the methodology for calculating fire risk in buildings and structures of various classes of functional fire hazard according to [17]. The methodology for evaluating the effectiveness of the proposed solutions to improve the system involves the following algorithm of actions:

- fire hazard analysis;
- establishing the frequency of occurrence of fire situations;
- construction of various scenarios for the development of fires;
- assessment of the impact of various fire scenarios on people;
- algorithm of the warning system and evacuation control;
- comparison of results before and after modification of the system.

The system is an automated software package that is designed to evacuate people during a fire, to prevent panic and crowds. Analyzing the work of various authors, it can be noted that the choice of the algorithm of the system requires individual development taking into account all the features of the building (number of storey, elevators, number of evacuation exits and stairs, etc.). It should be noted that most studies are inclined to algorithms with phased evacuation of people than to an algorithm with a one-time evacuation. The phased algorithm has significant advantages in evacuation due to the uniform distribution of human masses, which in turn helps to avoid the creation of significant congestion on the evacuation route, but does not completely eliminate them, since most people in these situations are prone to panic, and are not able to quickly take the right ones solutions. Therefore, the evacuation system should help people choose the right direction in such situations. The use of several types of alerts (sound, speech, light) and the direction of the trajectory of the movement of people (signs of evacuation exits of various types) helps to evenly distribute traffic flows and avoid panic.

Currently, there are 5 types of systems that differ in technical composition and method of action. Below is a description of the systems by type (Figure 3). This article proposes to supplement the type
5 system and introduce the concept of a system of controlling the movement of people, which can be used not only in case of fire, but also in case of other emergency situations.

An addition to the system is the implementation of the following components:

- dynamic pointers in the form of a pulsating LED strip;
- location map with options for movement;
- visual information with data on evacuation on the terminal devices of the integrated multimedia system (all television screens installed in the building).

Figure 3. The evolution of alert methods in various types of systems.

These technologies have been successfully tested in multifunctional complexes, large shopping centers, transport facilities, subways and are used for independent navigation by users in standard conditions of stay. To use the system in extreme situations, it must be supplemented by the mandatory installation of sensors to control the number of people on floors that will allow to make adjustments to the movement of people in real time, as well as to identify the presence of people who, for various reasons, cannot be evacuated on their own.

The functions of this system include:

1. Receiving a signal about the place of occurrence of an extremely situation (in manual or automatic mode).
2. Determination using active and passive (motion sensors) means of the number of people and the direction of their movement.
3. Calculation of the scenario of the movement of people, taking into account the total number of people on the floors, including the possibility of implementing several evacuation options.
4. Activation of the evacuation algorithm that meets the conditions in this particular scenario.
5. The direction of visual information about the evacuation through a comprehensive solution - Digital Signage IS-Media on the terminal devices of the multimedia system.

Figure 4 shows the functionality of the system for controlling the movement of people.
3. Results and Discussion

The final objective of the study was to carry out a calculation justification of the effectiveness of the proposed solutions for the modification of the system. For this, as an example, consider a tower located in the multifunctional complex Moscow-City, which houses metro stations, public space, hotels, shops, restaurants, entertainment centers, and offices. From the northeast, the site borders on the North entrance to the Central core, through which the main transport connection with the Central core is carried out, the North entrance is also a connection to the metro station. The plot area is 1,073 ha. The multifunctional complex consists of two towers of different heights. The first tower has 96 floors, the second tower has 63 floors. They are located offices, apartments. A warning system and type 5 evacuation control system was designed in the tower, which allows you to evenly distribute the flow of people during the evacuation and not create a crowd of people in different areas during the evacuation. Consider the principle of its operation in a situation when a fire occurs on the 23rd floor (Figures 5-6).

Figure 4. Design decisions of the system for controlling the movement of people in emergency situations at transport facilities.

Figure 5. An arrangement of passive means of counting the number of people who passed.
Figure 6. Model of the spread of hazards fire on the storey: a) after 9 seconds after the start of a fire; b) after 55 seconds after the start of a fire.

The system operation algorithm is shown in Figure 7. The notification interval is 10 minutes. It is designed in such a way that the main stream of people who are evacuated from the floors creates a minimum crowd. The first is the evacuation of the storey in which the fire occurred, then all the higher storey are evacuated, because flame spreads up. Next is the evacuation of storey that are located below the source of ignition.

Figure 7. The algorithm of the warning system and evacuation control.

Based on the modeling of the movement of people along the most favorable trajectories (Figure 8), the safety characteristics were calculated taking into account the premises, the number of people: individual fire risk, evacuation time.
Figure 8. Modeling the movement of people along the most advantageous trajectories on the storey where the fire occurred.

The calculation results (Tables 1 and 2) show that the main condition for safe evacuation of people - the evacuation time is less than the time of blocking the evacuation routes - is fulfilled in both scenarios.

Table 1. Summary calculation data on evacuation scenarios for existing and modified system.

| Name           | Fire frequency in a building | Conformity coefficient of automatic fire extinguishing installations | The probability of evacuating people | Fire protection system compliance coefficient | Individual fire risk |
|----------------|------------------------------|---------------------------------------------------------------------|-------------------------------------|-----------------------------------------------|----------------------|
| Existing system| 0.040                        | 0.900                                                               | 0.999                               | 0.8704                                        | 5.184·10⁻⁷           |
| Modified system| 0.040                        | 0.900                                                               | 0.999                               | 0.8704                                        | 5.671·10⁻⁷           |

Table 2. The results of the calculation of the evacuation time.

| Name          | Evacuation time (s) | Time from the start of the fire to the start of the evacuation (s) | The time of observation of the density of the flow of people (s) |
|---------------|---------------------|---------------------------------------------------------------------|---------------------------------------------------------------|
| Existing system| 2633                | 5.8                                                                | 183.2                                                         |
| Modified system| 2451                | 5.8                                                                | 137.5                                                         |

The time of crowding with maximum density does not exceed 6 minutes in both scenarios, which meets the requirements of regulatory documentation. With a modified system, the congestion time decreases by 182 s (3 minutes). This is due to the fact that the system, having analyzed the flow of evacuated using motion sensors, can change the evacuation algorithm and evenly direct people to the evacuation exits using visual information on the terminal devices of integrated multimedia and dynamic motion indicators. In turn, with a decrease in this indicator, the total time of evacuation from the building also decreases.
4. Conclusions
The main scientific and practical provisions obtained during the study of the problem situation considered in the work:

- the types of warning systems and people flow control in an emergency were identified and characterized, and the need to improve them was substantiated;
- the device of additional components of the vertical transport control system with the possibility of synchronization with related security systems, in particular with an access control and management system;
- calculation of the evacuation time for the existing and modified system;
- it was found that during evacuation it will decrease by 7%.

The results obtained in the work are advisable to apply not only in cases of fire, but also in the conditions of other emergency situations of natural, technogenic or anthropogenic impact at transport infrastructure facilities. A modified system, including the use of dynamic pointers, integrated multimedia, analysis of the direction of movement and the number of people will allow:

1. To help choose the right escape route for people based on the effect of virtual presence, which will reduce the level of stress.
2. Monitor the number of people remaining in the emergency zone.
3. Correct the density of the flows and evenly distribute them along the evacuation routes.
In turn, reducing the density of crowds reduces the risk of injuries and the time of evacuation.

References
[1] Shikhalev D V, Khabibulin R S, Lyubimov E M and Aleksin S A 2018 J. Issues of Risk Analysis 15(1) 82
[2] STO NOSTROY 2.35.73-2012 2014 Engineering networks of high-rise buildings. Integrated safety systems for high-rise buildings and structures (Moscow: National Association of Builders) p 191
[3] Dinh C H and Korol'chenko A Ya 2012 J. Proc. of Moscow State University of Civil Engineering 10 206
[4] Kholschevnikov V V 2018 J. Fire and Explosion Safety 27(1) 5
[5] Dement'eva M, Terekhin I and Lebedeva A 2018 MATEC Web of Conf. 251 06012
[6] Granovskiy E A, Lyfar V A, Vorona A P, Barbuca I M and Jarosz W 2011 J. Bezpieczenstwo i Technika Pozarnicza 24 59
[7] Dement'eva M and Dement'eva A 2018 E3S Web of Conf. 33 03067
[8] Yang L, Rao P, Zhu K, Liu S and Zhan X 2012 J. Safety Science 50(5) 1173
[9] Kasereka S, Kasoro N, Kyamakya K, Goufo E-F D, Chokki A P and Yengo M V 2018 J. Procedia Computer Science 130 10
[10] Abu Bakar N A, Adam K, Majid M A and Allegra M 2017 8th Int. Conf. on Inf. Technology 361
[11] Wysoczyński P and Adamski A 2011 J. Bezpieczenstwo i Technika Pozarnicza 24 121
[12] Papinigis V, Geda E and Lukošius K 2010 J. of Civil Engineering and Management 16(1) 131
[13] Kholschevnikov V V and Serkov B B 2017 J. Fire and Explosion Safety 26(9) 44
[14] Abu Bakar N A, Majid M and Adam K 2016 J. Advanced Science Letters 4(2) 400
[15] Sime J D 1999 J. Facilities 17(9-10) 313
[16] Chołuj L 2012 J. Bezpieczenstwo i Technika Pozarnicza 27 127
[17] Order EMERCOM of Russia N 382 2009 On approval of the methodology for determining the calculated values of fire risk in buildings, structures and structures of various classes of functional fire hazard (Moscow: Ministry of Justice RF) p 74