Justifying calculations of people warning and evacuation algorithms in case of fire in accordance with its source location variants and combustion development dynamic

S F Khrapskii, E A Bedrina

Omsk State Technical University, 11 Mira ave., Omsk, 644050, Russia
E-mail: bedrina_ea@mail.ru

Abstract. Modern warning and people evacuation management systems in case of fire are able to implement different notification options (with a start evacuation delay) and different people groups routing, which reduces their flows density and the critical congestions formation probability on the evacuation routes. For these systems potential technical capabilities practical realization, warning and evacuation algorithms are required in accordance with the fire source location, the combustion development dynamic, the characteristic parameters of the object and the evacuating people. Such algorithms generation is possible on the basis of information about the current values and fire hazards increase dynamic in the premises and on the evacuation routes. The necessary information can be obtained as a result of numerical studies using software tools that implement mathematical models of heat and mass transfer and gas dynamic processes, as well as the evacuating people flows movement processes in case of fire. One of the algorithms examples for alerting and evacuating people for the educational institution building is presented. The calculated data make it possible to predict and evaluate the people safe evacuation fundamental possibility in case of fire and to propose space-planning, technical and organizational solutions and measures for its successful implementation.

1. Introduction

In fires case in public buildings, issues of people timely warning about the fire and their safe evacuation organization are essential. The evacuation routes safety depends fundamentally on the fire location in the building and the combustion development dynamic. Modern fire warning and evacuation management systems (WEMS) of increased functionality [1] are able to implement different options (with a start evacuation delay) and different groups routing depending on the fire development scenario at the object. It minimizes the human flows jostle and confluence situations on the evacuation routes, thereby reducing their density and the critical congestions formation probability and “traffic jams”, and also take into account the exact location of the combustion source due to receiving a signal from the address fire detection system [2]. For the potential technical capabilities practical realization of such WEMS, algorithms for warning and evacuation should be added to their storage block in accordance with the fire location, the combustion development dynamic, the object and the evacuated people characteristic parameters [3].
2. Materials and Methods

The operation algorithms generation for WEMS enhanced functionality is possible on the current values information basis and the so-called fire hazards increasing dynamic in the premises and on the evacuation routes, the impact of which, by definition [4], can lead to injury, poisoning or person’s death. Such factors include an increased temperature of the gas-smoke environment, an increased toxic combustion products concentration, a reduced oxygen concentration, a visibility decrease in smoke (due the optical gas-smoke environment density increase) [4]. Obtaining of such information in real fire conditions is extremely difficult and extremely dangerous. However, the necessary information can be obtained as a computational studies result (numerical experiments) using software tools that implement mathematical models of heat and mass transfer and gas dynamic processes, as well as the evacuating people flows movement processes in fire case [5, 6, 7, 8, 9, 10].

3. Experimental section

The FDS software package was used to calculate the fire hazards values [11, 12, 13, 14], implementing the so-called field modeling of heat and mass exchange and gas dynamic during burning action [8, 15]. To calculate the people evacuation processes, the Pathfinder software package was used [16, 17, 18], which implements an individual-flow model of human movement [5, 6, 7, 8, 9, 10].

The calculation results obtained on the basis of these software packages allow to develop algorithms for alerting and evacuating people in fire case for almost any building. We present one of such algorithms examples.

Since the greatest people safe evacuation problems arise when there are fires in buildings with a mass presence of people [19, 20, 21, 22, 23], then the educational institution building was chosen for the calculation study. The three-storey building under consideration (Fig.1, 2) has an average complexity configuration, similar to the relative principal (main) entrance/exit (1 in Fig. 1, 2). The classrooms are located along the corridor opposite each other. The number of students in the classrooms is shown in Fig. 1, 2 by the sum formula, for example 25 + 25 means that there are 25 people in each of the two opposite classrooms. The building is equipped with additional emergency exits (2 and 3 in Fig. 1, 2). The same and typical fire load for similar buildings in terms of type, mass and combustion parameters is assigned for all premises [24]. In the object internal volume, groups of premises are allocated, which have unique individual addressing in alarm and warning systems (the so-called address fire alarm control zones [2] and address fire warning zones [1], which are indicated in Fig. 1, 2 as numbers 1-12. Thus, each of the premises’ groups (zones) is uniquely identified.

The graphic diagrams (Fig.1, 2) show two options for the fire location: the first option (Fig.1) – on the ground floor at the principal building exit (the fire development first scenario), the second option (Fig.2) - on the second floor (the fire development second scenario). As a calculations result, the optimal people evacuation directions and the necessary time intervals T (s) before the movement start are obtained (Fig. 1, 2) for each of the premises’ groups where it is possible to evacuate all people before the time when the evacuation routes and exits from the building will be blocked by fire hazards [3, 7, 8]. At the same time, the flows confluence and people jostle situations on the evacuation routes exits were minimized, which not only slows down the movement speed, but even leads to their blocking [7, 8].

4. Discussion

The computational studies results presented in Figs. 1, 2 show a significant difference in the warning and evacuation algorithms depending on the seat of fire location. In the first variant, evacuation is possible only through additional exits 2 and 3, since the main exit is blocked by fire. Concurrently, such required flow directions and evacuation start delays times were obtained for all premises groups, which make it possible to exclude people jostles and people flows confluences on evacuation routes and exits with a minimum total safe evacuation time for the specified parameters. This is attained by the corresponding increase in the evacuation start delay time for the second floor.
premises compared to the first floor premises and for the third floor premises compared to the second floor premises.

Figure.1. Evacuation algorithm graphical diagram for the fire development first scenario (see the legend in the text)

On each of the floors (except the first), people from the premises in dead-end corridors sections with worse fire hazards conditions compared to through sections of building middle part are allowed to pass earlier. People from the most dangerous central rooms of the first floor, located in the fire close proximity, should be evacuated without any delay through exits 2 and 3.

Note that the delay times difference indicated in Fig. 1 in the symmetrical building left and right parts for the second and third floors conditionally demonstrates these delays possible range, at which safe evacuation is attained.

For evacuation in the fire development second scenario (Fig. 2), all exits from the building are available, including the main one. Due to this, the evacuation load on emergency exits is reduced. The higher the floor there is a combustion, the generally less dangerous the fire development scenario is. For example, if a seat of fire is located on the second floor, people on the first floor may be in relatively normal conditions for a long time. Therefore, for rooms in dead-end sections of first floor corridors the maximum possible evacuation start time delays should be set in order to allow passing of upper floors’ flows to the exits and not create critical congestions on the stairs. At the same time, the time delays for the premises in the building left part are significantly less than in the right one, since the fire is located at the stairs in the building left part and people from this part of the building should be allowed to the exits earlier. The people movement from the rooms of the central and right parts of
the second floor and after them from all the third floor rooms should be carried out only by the right staircase (since the left staircase is quickly blocked by the fire located next to it).

For the presented example of the building, it was possible to obtain the safe evacuation optimal parameters values. But when the initial data changes (for example, increase of building storeys number, the fire load parameters and people number) and achieves certain values, the safe evacuation implementation from a certain point in time is unrealizable due to the fire hazards excess of their critical values for people on the escape routes and exits. An increase of corridors dead-end sections length and the people number in rooms with exits to these corridors leads to a similar outcome (it is characteristically for many objects), especially when the fire source is located near the exit from such a corridor. In these cases, in order to carry out safe people evacuation, it is necessary to change the building space-planning parameters, for example, to expand the existing evacuation routes, to organize additional paths and exits. One of the most effective measures in this regard (both in evacuation safety and financial costs terms) it is the emergency stairs arrangement from the building exterior sides.

5. Conclusions

The computational studies results using modern software systems allow:

to determine and justify the optimal algorithms parameters with regard to safety for the warning systems functioning and people evacuation management in fire case;

to predict and evaluate the fundamental people safe evacuation possibility in fire case and to propose space-planning, technical and organizational solutions and measures for its successful implementation.

References

[1] Set of rules «Systems of fire protection. System of annunciation and management of human evacuation at fire. Requirements of fire safety» (approved by the order of the Ministry of Emergency Situations No. 173 from March 25, 2009)

[2] Set of rules «Fire alarm systems and automation of fire protection systems. Designing and regulations rules» (approved by the order of the Ministry of Emergency Situations No. 582 from July 31, 2020)

[3] Samoshin D A, Kholshchevnikov V V 2016 Problems of regulation of time to start evacuation. Fire and Explosion Safety vol 25 no 5 pp 37–51

[4] Federal Law «Technical regulations for fire safety requirements» No. 123-FZ on 22 July 2008 (edited on 29 July 2017)

[5] Kolodkin V M, Galiullin M E 2016 Software algorithms that implement the foot traffic model in the building evacuation management system. Fire and Explosion Safety vol 25 no 10 pp 75–85

[6] Parfenenko A P 2014 Methodology for modeling human movements and practice of programming their movement during evacuation. Fire and Explosion Safety vol 23 no 12 pp 46–55

[7] Kholshchevnikov V V, Parfenenko A P 2015 Comparison of different models of the movement of human flows and results of program computer systems. Fire and Explosion Safety vol 24 no 5 pp 68-75

[8] Kholshchevnikov V V, Parfenenko A P 2014 About modeling of evacuation of people and dynamics of fire hazards in purpose of normalization evacuation routes. Technology of Technosphere Safety no 1 (53) p 8

[9] Kirik E S, Degtyarev A A, Litvintsev K Y, Kharlamov E B and Malyshev A V 2014 Mathematical modeling of fire evacuation. Mathematical Models and Computer Simulations vol 26 (1) pp 3–16 (in Russian).

[10] Samoshin D A, Deryugin D P 2015 Analysis of mathematical models of the pedestrian flow of people evacuated (part 1). Technology of Technosphere Safety no 5 (63) pp 90–97

[11] McGrattan K, Hostikka S, McDermott R, Floyd J and Vanella M 2013 Fire Dynamics Simulator (Version 4) Technical Reference Guide. Gaithersburg: National Institute of Standards and Technology 149 p
[12] McGrattan K, McDermott R, Weinschenk C, Overholt K, Hostikka S and Floyd J 2013 Fire Dynamics Simulator User’s Guide: NIST Special Publication 1019. Sixth Edition. Gaithersburg: National Institute of Standards and Technology 262 p

[13] Korhonen T, Hostikka S 2009 Fire Dynamics Simulator with Evacuation: FDS+Evac — Technical Reference and User’s Guide / VTT Working Papers 119. Espoo: VTT Technical Research Centre of Finland

[14] FDS+Evac Software. VTT Technical Research Centre of Finland. URL: https://code.google.com/p/fds-smv

[15] Nedryshkin O V, Gravit M V 2018 Software complexes for modeling of dangerous fire factors. Fire Safety no 2 pp 38–46

[16] Pathfinder: Technical reference. Thunderhead engineering 2009. URL: http://www.thunderheadeng.com/pathfinder

[17] Pathfinder. Agent Based Evacuation Simulation. URL: http://www.thunderheadeng.com/pathfinder

[18] Grigoras Z C 2014 Analysing the human behavior in a fire drill. Comparison between two evacuation software: FDS+Evac and Pathfinder // Bulletin of the Transilvania University of Brasov CIBv vol 7(56) Special Issue no 1 pp 103–110

[19] Merkushkina T G, Samoshin D A, Khasueva Z S and Zykova M Y 2015 Features evacuation of people from modern office buildings in case of fire. Technology of Technosphere Safety no 5 (63) pp 73–81

[20] Shields T J, Boyce K E and Samoshin D A 2002 Study of evacuation from retail stores. Fire and Explosion Safety vol 11 no 6 pp 57–66

[21] Gravit M V, Karkin I N, Dmitriev I I, Kuzenkov K A 2019 Simulation of evacuation process in high-rise buildings and structures with using passenger elevators. Fire and Explosion Safety vol 28 no 2 pp 66–80

[22] Kholschevnikov V V, Samoshin D A 2014 Problems of fire safety of disabled people in buildings with their mass presence. Fire and Explosion Safety vol 23 no 8 pp 37–52

[23] Samoshin D A, Slyusarev S V 2016 To a question of static and dynamic dimensions of pedestrians of various groups of mobility. Proceedings of Moscow State University of Civil Engineering no 4 pp 84–93

[24] Abashkin A A, Karpov A V, Ushakov D V, Fomin M V, Giletich A N and Komkov P M 2014 et al. Handbook on application of “Method for determining the calculated values of fire risk in buildings, structures and structures of various classes of functional fire hazard”. Moscow, All-Russian Research Institute for Fire Protection of Emercom of Russia Publ. 226 p