Numerical modeling methods for safety assessment at public facilities

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Abstract. The assessment of the protected evacuation of the population from the fire zone at social facilities in the service sector on the basis of numerical modeling methods has been carried out. The time of safe evacuation of people from the object on the basis of a basic mathematical model for monitoring fire hazards for a specific social object has been regulated. Correlations between the degree of heat and the fire duration have been recorded. Partial concentration of \(O_2\), \(CO_2\), CO, HCl, measures of smoke aerosol opacity from the fire duration using "Fogard" software package configured for simplified analytical model of human flow have been captured. On the basis of the developed mathematical model of fire development design solutions that provide a secure evacuation of the population from the object have been proposed. The calculation of the blockade duration of routes and passageways for sending people out of the fire zone was made using deterministic fire indicators has been performed.

1. Introduction

The purpose of this study is to monitor the compliance of building projects with fire protection regulations using the Fogard software complex.

In accordance with the regulatory legal framework [1-4], in particular art. 53 [2] according to the planning norms of the building and architectural component of the design in three components: linear, longitudinal and modular dimensions and efficient implementation of evacuation routes and passages, the protected object guarantee security when sending the population from the premises of a public facility in the service sector. The object of research is the fire safety of the "Rubin" multifunctional shopping complex with a built-in underground parking in the city of Tver. The object is planned to be three-storey with one underground floor.
2. Computational and analytical stage based on numerical modeling method sand Fogard software complex

2.1. Determination of the required evacuation time using the "Fogard" software complex according to a simplified analytical model of the human flow movement

The results of the statement of the mandatory duration of sending the people out of the fire zone are illustrated in table 1. Designations: FH – fire hazards or deterministic factors (DF); \( \tau_{reg} \) – indispensable or necessary, or required duration of sending the people \([3, 4]\).

**Table 1. Results of establishing the required duration of the people sending.**

| Calculated design DFs | \( \tau_{reg} \), s | Calculated design DFs | \( \tau_{reg} \), s |
|-----------------------|---------------------|-----------------------|---------------------|
| Increased degree of hotness | 350.8               | CO cumulation          | 586.4               |
| The loss of visibility | 156.9               | CO\(_2\) cumulation    | Safely              |
| Reduced cumulation of O\(_2\) | 383.7               | HCl cumulation         | 309.5               |

The designations used in the calculations of this paper are regulated in accordance with [1], we quote: "\( Q_n \) is the lowest heat of combustion when water is in the form of steam after combustion of the material, J/kg; \( V_f \) is the linear velocity of flame propagation over the material surface, m/s; \( \psi \) is the specific mass rate of material burnout, kg/(m\(^2\)s); \( D \) - smoke generating ability or smoke production coefficient, m\(^2\)/kg; \( \text{LO}_2 \) - specific consumption during combustion of 1 kg of substances, kg/kg; \( \text{LCO}_2, \text{LHCl} \) - specific yield of toxic gases during combustion of 1 kg of substances, kg/kg". Clarification: \( V_f \) of the initial stage of ignition in the initial stage of a fire is postulated up to 10 minutes. The required time interval for sending the people from the fire zone is standardized, taking into account the protection multiplier 0.8 [1].

Parameters of the combustible load “Car \((0.3 * \text{rubber, gasoline}) + 0.15 * \text{leather, PU foam}) + 0.1 * \text{enamel})”: \( Q_n = 31700000 \text{ J/kg}; \ V_f = 0.0034 \text{ m/s}; \ \psi = 0.0233 \text{ kg/(m}^2\text{s}); \ D = 487 \text{ m}^2\text{/kg}; \ \text{LCO}_2 = 0.097 \text{ kg/kg}; \text{LO}_2 = 1.295 \text{ kg/kg}; \text{LHCl} = 0.0109 \text{ kg/kg}; \text{HCl} = 2.640 \text{ kg/kg}.\n
The results of stating the duration of people sending are illustrated in table 2. Clarification: all designations and clarifications in table 2 are the same as in table 1.

**Table 2. Results of the statement of the required duration of people sending.**

| Calculated FH | \( \tau_{reg} \), s | Calculated FH | \( \tau_{reg} \), s |
|---------------|---------------------|---------------|---------------------|
| Increased degree of hotness | 340.0               | CO cumulation  | 568.4               |
| The loss of visibility | 152.1               | CO\(_2\) cumulation | Safely |
| Reduced cumulation of O\(_2\) | 371.9               | HCl cumulation | 300.0               |

Characteristics of flammable materials “Packing: paper + cardboard + polyethylene + polystyrene \((0.4 + 0.3 + 0.15 + 0.15))”: \( Q_n = 235400000 \text{ J/kg}; \ V_f = 0.002 \text{ m/s}; \ \psi = 0.0132 \text{ kg/(m}^2\text{s}); \ D = 172 \text{ m}^2\text{/kg}; \ \text{LCO}_2 = 0.112 \text{ kg/kg}; \text{LO}_2 = 0.679 \text{ kg/kg}; \text{LHCl} = 0.0037 \text{ kg/kg}; \text{HCl} = 1.7 \text{ kg/kg}.\n
2.2. Basic mathematical model for monitoring fire hazards for a specific social object - the "Rubin" multifunctional shopping complex with a built-in underground parking in the city of Tver

The location of the fire start is assumed to be room "100". Correlations between the DF characteristics and the duration of the fire are shown in figure 1-6. Graphs of the FH values dependence on the fire duration are shown in figure 7-12. The use of information technologies is noted in works [5-11].

Fuel load parameters of the building I-IICO, furniture + fabrics": \( Q_n = 14700000 \text{ J/kg}; \ V_f = 0.0054 \text{ m/s}; \ \psi = 0.0145 \text{ kg/(m}^2\text{s}); \ D = 82 \text{ m}^2\text{/kg}; \ \text{LCO}_2 = 0.022 \text{ kg/kg}; \text{LO}_2 = 1.285 \text{ kg/kg}; \text{LHCl} = 0.006 \text{ kg/kg}; \text{HCl} = 1.437 \text{ kg/kg}.\n
2
Figure 1. Correlation of the degree of heat with the fire duration.

Figure 2. Correlation of partial O$_2$ concentration with the fire duration.

Figure 3. Correlation of the smoke aerosol opacity with the fire duration.

Figure 4. Correlation of HCl partial concentration with the fire duration.

Figure 5. Correlation of partial CO$_2$ concentration with the fire duration.

Figure 6. Correlation of the partial CO concentration with the fire duration.
3. Calculation of Workforce and Means for Extinguishing a Possible Fire by Divisions of the State Fire Service and Economic justification

The most difficult situation could happen when a fire occurs on the minus 1 floor of the parking. The most dangerous scenario, for example, is a car fire.

The linear speed of fire propagation for vehicles is assumed $V_l = 0.408$ m/min. To extinguish a fire, a solution of medium-sized foaming agent is used.
The required supply intensity of fire extinguishing agents for vehicles is \( I_{\text{reg}} = 0.1 \, \text{l/c} \cdot \text{m}^2 \) [12],
\[
\tau = 2 + 1 + 10 + 5 = 18 \, \text{min}.
\]
Next, we calculate the path traversed by fire:
\[
R = 0.5 \cdot V_i \cdot 10 + V_f \cdot (\tau - 10),
\]
\[
R = 0.5 \cdot 0.408 \cdot 10 + 0.408 \cdot (18 - 10) = 5 \, \text{m}.
\]
Based on the parking size we calculate the area of the fire:
\[
S_u = \pi R^2,
\]
\[
S_u = 3.14 \cdot 5^2 = 80 \, \text{m}^2
\]
We determine the number of hoses to localize and extinguish a fire in a given area:
\[
Q_{\text{reg}} = I_{\text{reg}} \cdot S_u = 0.1 \cdot 80 = 8 \, \text{l/s}.
\]
To colocalize the fire at this stage, you will need the following number of hoses:
\[
N_{h,SFS-600}^{m} = S_m I_s / Q_h,
\]
\[
N_{h,SFS-600}^{m} = 80 \cdot 0.1 / 6 = 2 \, \text{SFS-600 hoses}.
\]
Hoses can be supplied by two fire truck brigades. We determine the amount of foaming agent needed to extinguish a fire in this area:
\[
W_{\text{foam}} = N_{h,SFS-600}^{m} \cdot C \cdot q_{\text{SFS-600}}^{\text{foam}} \cdot \tau_{s} \cdot K_{\text{foam}},
\]
\[
W_{\text{foam}} = (2) \cdot 1 \cdot 0.06 \cdot 6 \cdot 10 \cdot 3 = 648 \, \text{l} = 1296,
\]
where \( C \) is the percentage of foaming agent in the solution (6%); \( q_{\text{SFS-600}}^{\text{foam}} \) is the consumption of the foaming agent by one fire truck generator, l/s; \( \tau_{s} \) is the standard operating time (10 min.); \( K_{\text{foam}} \) is the foaming agent safety factor.

Consumption of \( \text{H}_2\text{O} \) to eliminate the fire source:
\[
Q^m = N_{h,SFS-600}^{m} \cdot Q_{h,SFS-600} = 1 \cdot 5.64 = 5.64 \, \text{l/s}.
\]
Consumption of \( \text{H}_2\text{O} \) for the purpose of preservation, implementation of reconnaissance, sending people and property out of the fire zone:
\[
Q^z = N_{h}^z \cdot Q_h = 2 \cdot 3.5 + 2 \cdot 5 = 17 \, \text{l/s}.
\]
Verifying the equipment of the \( \text{H}_2\text{O} \) object:
\[
Q_{\text{water supply}} = 100 \, \text{l/s} > Q_f = 23 \, \text{l/s}.
\]

4. Findings
During the advance of the flame in the Parking 1 on the -1 floor of a multi-purpose public facility, two fire truck brigades do not guarantee its step-by-step elimination. All fire extinguishing operations are carried out using gas and smoke protection measures.
To extinguish a possible fire in the parking on the minus 1 floor of a multifunctional public center, as well as to conduct work on the exploration of premises, evacuation of people and property, it is necessary to automatically send forces and means of the State fire service by call No. 2.

As a result of the calculation, it is established: 42100 rubles will be needed to cancel the fire source, the loss will 1105700 rubles, and the procedures for preventing the origin of the fire source will require 177,000 rubles.

The implementation of these measures will increase the fire safety of shopping and entertainment centers, reduce the risk of fires, injuries and deaths, and avoid material damage.

5. Conclusion

Verification calculations of the main condition for safe people evacuation showed that it is fulfilled when the proposed engineering and compensating measures for organizing evacuation are performed. Based on the mathematical model of the fire, design solutions have been developed to ensure the safe people evacuation from the object. The calculation of the routes and passageways blockade duration using deterministic fire indicators has been made.

The economic calculation showed that the efficiency is 6.5. Material damage will be minimal. As a result, design solutions that ensure the safe people evacuation from the building (people have enough time to leave the building premises) have been developed.

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