Field modeling of heat transfer in atrium

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Abstract. The results of calculating fire risk are an important element in the system of modern fire safety assessment. The article reviews the work on the mathematical modeling of fire in the room. A comparison of different calculation models in the programs of fire risk assessment and fire modeling was performed. The results of full-scale fire tests and fire modeling in the FDS program are presented. The analysis of empirical and theoretical data on fire modeling is made, a conclusion is made about the modeling accuracy in the FDS program.

1. Introduction

The calculation of the calculated values of fire risk is realized by various software complexes. One of the key parameters in the calculation of fire risk is the determination of the time to block the evacuation routes by dangerous fire factors (hereinafter referred to as "DFF"). Time is determined with the help of mathematical modeling tools, which are based on integral, zone or field models of the distribution of the DFF. Another key parameter is the dynamics of evacuation in case of fire and movement of human flows in emergency situations. This task remains difficult to solve due to the psycho-emotional impact of the fire on the individual and the crowd.

From the point of view of thermal physics, combustion - a set of processes of different physical nature, closely interacting with each other, and for modeling heat and mass transfer in the combustion process, adequate and effective means of calculating turbulent flow and radiative transport in the radiating and absorbing medium are necessary. The variety of works devoted to the development of simplified models, only in single cases imply the possibility of taking into account the mass burnout rate [1]. It should be noted that turbulent fluctuations play an important role in the emission of thermal radiation, for which two approaches are possible: the introduction of corrections that contain correlations of radiation intensity and temperature, or averaging the corresponding quantities using the probability density function [2-4]. We also note that the amplitude of the fluctuations of all parameters in natural convective combustion can be very high and reach 50% of the mean value [5-7].

2. Tools for calculating fire risk in the room

The methods used to determine the calculated values of fire risk in buildings, structures and structures of various classes of functional fire hazards used in the methodology approved by the Ministry of Emergency Measures can be divided into integral, zone and field models, which describe the dynamics of the gas environment (density, temperature, oxygen concentration and combustion products, optical density) in time during a fire in the room.
Integral mathematical models of fire (hereinafter - MMF) are based on the laws of conservation of mass and energy, which are expressed in the form of the basic equations of the problem and the conditions for the uniqueness of the solution.

In zone models, the room is divided into the upper, lower zones and the zone of the convective column, for each of these zones an integrated MMF is compiled. The calculation performed for each zone separately should be more accurate than for the entire room. In the works of Puzach S.V. “A modified band model is proposed for calculating the thermogasdynamics of a fire in a room”, which takes into account the shape of the convective column formed above the combustion source. The obtained results have increased the accuracy of calculations, incl. smoke removal. The basis for the field models of fires is the equations expressing the laws of conservation of mass, momentum, energy and mass of components in the small control volume under consideration.

At present, the Fire Dynamic Simulation program (FDS) is the most widely used on the basis of the field model as a simulation tool for the PFD. For the first time, the FDS settlement model was publicly available in 2000. FDS numerically solves Navier-Stokes equations for low-speed temperature-dependent flows. The model is a system of partial differential equations, including the equations of conservation of mass, momentum and energy, is solved on a three-dimensional regular grid and describes the spatio-temporal distribution of the temperature and velocities of the gaseous medium in the room, the concentrations of the components of the gaseous medium (oxygen, combustion products, etc.), pressures and densities [8-10].

3. Comparison of the results of full-scale tests and the FDS model
Professor Chow VK from the University of Cambridge published the results of field fire tests [11]. The parameters of the test facility and the location of the thermocouples are shown in Figure 1. The heat flux reaches 2 MW, the flammable liquid is ethanol (the area of the pallet $S = 0.51$ m$^2$, $V = 16$ liters, 6 pallets). Experiment Chow V.K. modeled with FDS. Chow V.K. conducted a series of full-scale tests, in this paper we compare the results of modeling work [11].

The model of the test setup was created using the PyroSim program, Figure 2 shows its model in 3D. The calculated grid is divided into 4 fields of 36 192 cells. The volume of one cell is 0.125 m$^3$. 

![Tested atrium](image)
Figures 3 - 4 show the results of visualization of temperature fields in the Smokeview program, convective and radiant heat flow.

The graph (Figure 4) of the convective and radiative heat flux shows the discrepancy between the results of calculation of the experimentally obtained data and the simulation in FDS 6.5.3. In [12], a comparison of the spread of fire between FDS simulation results and experimental data is made, the results of the study confirm the validity of the FDS program. Some inconsistencies in the results obtained by the FDS program and in the recorded results in field trials have been revealed. In the study [13], the authors carry out a series of experiments and simulate them in FDS. The results are presented in the form of graphs, which show that there is a discrepancy between the full-scale test data and the simulation.
At the present time, the simulation of the RPC using the FDS program is considered correct and allows determining the time of blocking the evacuation output of the DFF. The results of calculations are used to justify acceptable fire risk in project documentation, during construction, reconstruction and declaration of protection objects.

4. Conclusion
The simulation of the burning process of ethanol in the construction with the atrium, carried out by the authors of the article, partially replicates the results of the experiments of Chow. The difference from the data obtained is due to the lack of accurate data on the experimental conditions. In [13], the simulation results are also presented in comparison with field trials, the correctness of calculations for the field model in FDS is stated, but also cases of discrepancy between modeling data and field experiment are noted. At present, there is no such program that correctly describes the actual tests of different configurations. In this direction, the prospects for the development of software complexes for calculating the DFF are laid [14 – 15].

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