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Investigation of the Fire-Preventing Eaves Effectiveness to Prevent the Fire Spreading by Vertical Building Structures of High-Rise Buildings

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Abstract. The results of using the FDS modeling during validation and verification of fire-preventing eaves constructive parameters that act outside of a facade and are located on border of fire-preventing compartments on a contour of high-rise buildings with conditional height more than 73.5 m are showed. Using FDS modeling, a typical model of a high-rise public building was built, the fire load inside buildings was reproduced and the destruction criteria of external light openings (windows) were verificated as an integral factor of fire spreading on external vertical building structures of high-rise buildings. A study of the eaves structural parameters effectiveness and their impact on the fire prevention by vertical building structures under the same conditions of fire spreading. Comparative dependences of heat distribution of house facade are constructed, and the duration of their critical values achievement is defined. The data obtained as a result of FDS modeling under the same conditions are analyzed and conclusions are made about the effectiveness of fire facade eaves design parameters that touch on fire compartments and ways to further design improvement for preventing fire in high-rise buildings. These studies are aimed to be used by the design institutions in the design parameters development of fire-preventing eaves, which protrude beyond the facade and touch on fire compartments along the contour of high-rise buildings, as well as to improve the regulatory framework building for fire safety.

INTRODUCTION

The fire spreading on the high-rise buildings facades is one of the most dangerous types of fire development, due to its rapid flame spreading, complexity of extinguishment, sufficient oxygen, as well as additional wind effects that encourage its rapid spread on facade structures. The statistics analysis of fires, their causes and consequences in high-rise buildings over the past ten years in Ukraine showed that the number of fires in high-rise buildings and the number of victims are increasing every year due to the constant annual increase. It should be noted that in recent years the number of fire loads in the middle of public and residential high-rise buildings has increased significantly. A large number of electrical appliances, gadgets, small electric vehicles (electric scooters, electric monocycles, etc.) can be possible sources of fire, which in the event of a fire can cause a rapid spread of fire inside the room. It should also be understood that with the development of high-rise construction has significantly increased the number of types of facade systems, structures for their implementation and fastening, as well as the materials from which they are made, which can also affect the spread of fire by external structures. Table 1 shows statistics of fires in 73.5 metres high-rise buildings in 2010-2020 in Ukraine.

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TABLE 1. The main statistical indicators of the fires state in high-rise buildings during 2010-2020 in Ukraine.

Indicator	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number of fires	47	43	65	56	66	71	77	83	90	109	112
The number of dead people	0	0	1	0	1	1	0	0	1	0	3
Number of injured people	0	2	5	1	5	6	7	2	8	4	12

In addition, the analysis of fires and their consequences in Ukraine and abroad shows that most fires that occurred in high-rise buildings are accompanied by the spread of fire on the facades, which made it impossible to quickly elimination and significantly complicate the work of fire and rescue units and special fire-fighting equipment usage. The fire spread on the external vertical building structures of high-rise buildings also made it impossible to eliminate it at the initial stage, with the use of fire protection systems, which are equipped with high-rise buildings. Figure 1 shows photos of the most highly publiciezed fires that occurred in high-rise buildings in 2019-2020 and were accompanied by the fire spread on the facade.

(a) (b) (c)

FIGURE 1. Photo of fires in high-rise buildings that occurred in 2020: (a) - fire in Kyiv, 16.12.2019 (Ukraine); (b) - fire in Sharjah, 05.05.2020 (United Arab Emirates); (c) - fire in Ulsan, 09.10.2020 (South Korea).

In this manner, the task is to investigate the possible design measures to prevent fire spreading by vertical building structures of high-rise buildings.

ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

In articles [1-2], the analysis of the fires causes and consequences in high-rise buildings is given, and also the influence of constructive parameters of facade fire-preventing eaves that touch on fire compartments for fire prevention in high-rise buildings by means of FDS modeling is investigated. The results have shown that the presence of a fire-preventing eaves that meets the requirements [3-4] reduces the actual temperature at the level of the upper floor below which the fire actually occurred by 45-47%. Nevertheless, the research has shown an increase in the temperature distribution area of heating on the facade surface by 30-35%, that is a negative phenomenon, and can be explained by direct contact of the fire flame with non-flowing obstacle.

The purpose of the work [5] was to develop a mathematical model of fire spreading in a three-story building during full-scale fire-response tests; research of accuracy and reliability of parameters of temperature modes of fire in separate premises of the building. A numerical experiment was conducted to model full-scale tests of premises with fire in a three-story building using computer gas-hydrodynamics methods.

Paper [6] considers issues related to fire hazard of constructions of external walls fit with façade heat insulation and finished with rendering which is dependent on constructive solution of the heat insulating system and type of heat insulating material. Appropriate works aimed at use of “Fire Dynamics Simulator” (FDS) software for the computer simulation of fire spread across façade system surfaces and comparison of experimental and calculated data were analyzed.

The authors of the works [7-9] investigated the influence of horizontal obstacles at different heights between unprotected openings on the facade of the building on the spread of external fire experimentally and compared the data using the numerical FDS instrument. It was concluded that the FDS version 6.2.0 can reproduce experimental results with a high level of detail.

The analysis of foreign building standards or scientific researches on the effectiveness of fire-preventing eaves showed that there are no recommendations or a single approach to the design parameters of fire-preventing eaves, which are on the high-rise building facade, futhermore, according to the research [10] the length of the protective structure should not be less than 1.2 m. Figure 2 shows an example of structural provisions based on research [10] to prevent the fire spreading by vertical building structures.

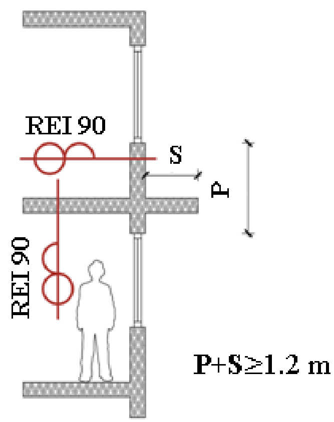


FIGURE 2. Example of precautionary measures to prevent the spread of fire by vertical building structures.

Along with this, taking into account the reserch [4], the question arises not only of the most effective value of the length of the eave, namely its shape as an integral part of preventing the fire spreading and reducing the temperature distribution of heating the facade surface.

THE PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this article is to identify the influence of structural parameters of facade fire-preventing eaves, the effectiveness of fire prevention by vertical building structures in high-rise buildings based on FDS modeling.

To achieve this purpose, the following tasks were solved:

- to develop a standard model of a facade and front fire-preventing eaves of various shape using the FDS software package on the basis of the analysis of the existing constructive decisions of fire-preventing front eaves in high-rise buildings;

- to determine the impact of the effectiveness of the design parameters of facade fire-preventing eaves and ways to improve their design to prevent the fire spreading in high-rise buildings under the same initial conditions of the experiment.

MATERIAL AND METHODS

For simulation and study of the temperature distribution on the facade of a high-rise building with different types of fire-preventing eaves, a model of a 23-storey building was created. Monolithic “heavy concrete” type with 2280 kg/m^3 density, 2.04 kJ/(kg·K) specific heat and 1.35 W/ (m · K) thermal conductivity was chosen as the basis of the building construction material. The light openings (windows) of the house are filled with glass, with a density of 2500 kg / m^3, with a specific heat of 0.67 kJ/(kg · K) and a thermal conductivity of 0.061 W / (m · K). The characteristics of the facade cladding material of a high-rise building model were not taken into account, conditionally assuming that in accordance with the requirements of building codes, they must be non-combustible. The calculated grid FDS of the model is 25 cm^2, that is due to the geometric dimensions of the building model and the multiplicity of the grid cell size is relative to the geometric parameters of the eave. According to the simulated fire scenario, it occurs on the floor located directly under the facade fire-preventing eave, with one window open in the room, and the generated heat flow and flames spread freely from the windows of the apartment.

It is assumed that the fire occurs in the center of the room and is equidistant from all walls of the room, the fire load of which is 365 kW/m^2 with a maximum burning temperature of 1190 °C. The flame spreads indoors at a speed of 0.22 m/s according to the recommendations [11-13]. The calculations did not take into account the operation of fire extinguishing or smoke removal systems, that is why the fire spreaded freely throughout the modeling duration.

Figure 3 shows the basic model of the high-rise building fragment and the model of room with fire load.

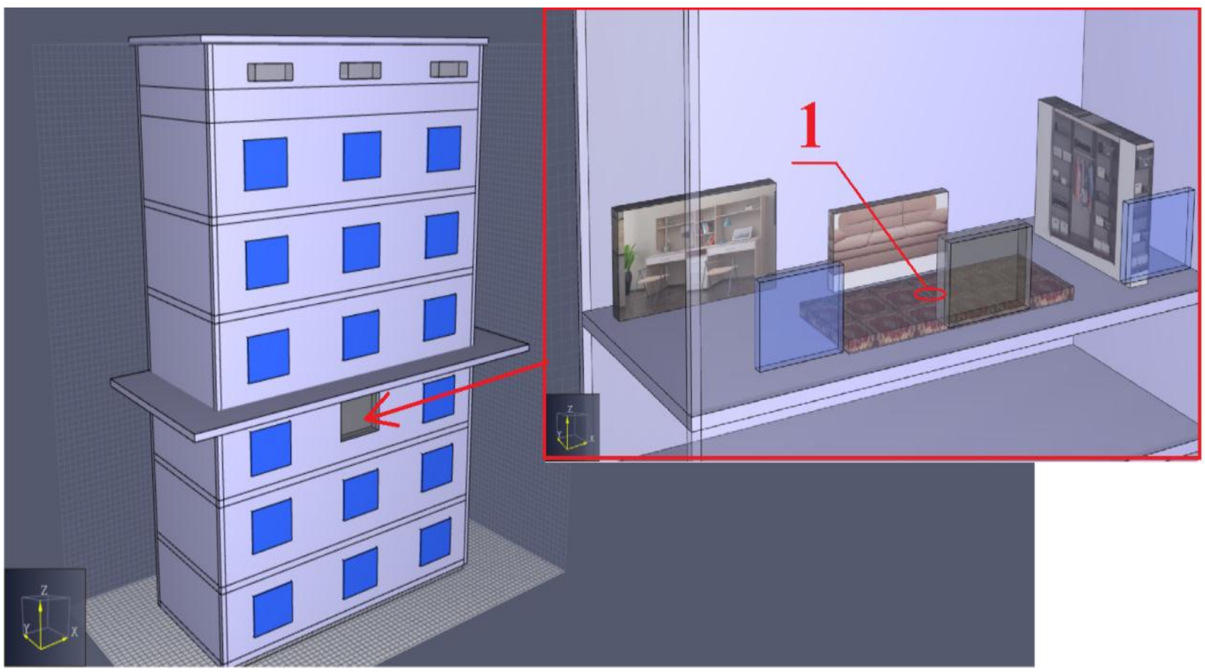


FIGURE 3. Building model and the place of the fire initial center during the research: (1) - the fire center in the room.

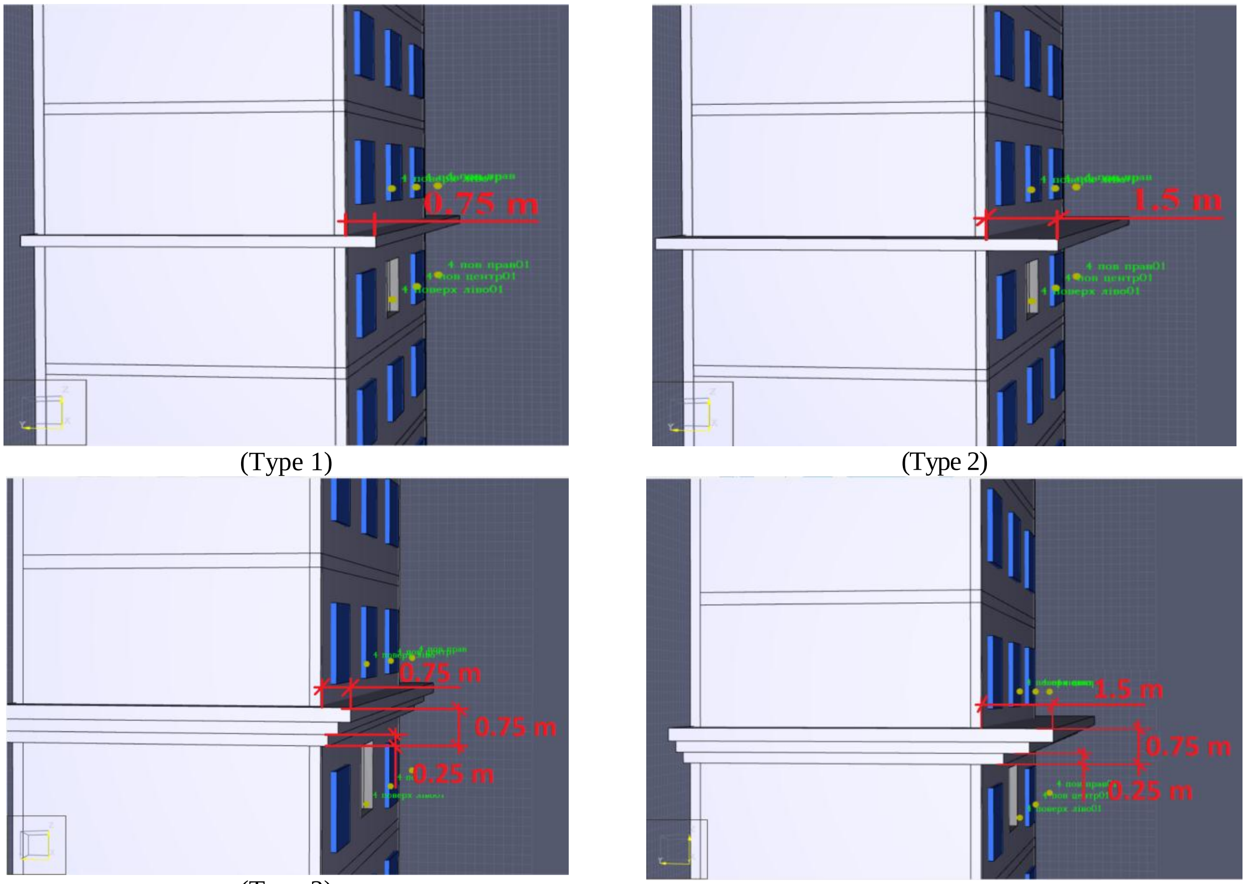
The limiting value criterion of the facade heating temperature is 250 °C, which corresponds to the deformation temperature of the material structure with the lowest temperature resistance, namely the design of plastic windows according to data [14].

RESULTS AND DISCUSSION

During the modeling of the facade fire-preventing eaves effectiveness to prevent the fire spreading by vertical building structures in high-rise buildings, the following types of structural forms were researched:

- type 1, a direct fire-preventing eave along the contour of the model house, which protrudes beyond the facade by 0.75 m;
- type 2, a direct fire-preventing eave along the contour of the model house, which protrudes beyond the facade by 1.5 m;
- type 3, round octagonal eave along the contour of the house, which protrudes beyond the facade by 0.75 m;
- type 4, round octagonal eave along the contour of the house, which protrudes beyond the facade by 1.5 m;

Figure 4 shows the researched models of facade fire-fihgting eaves.

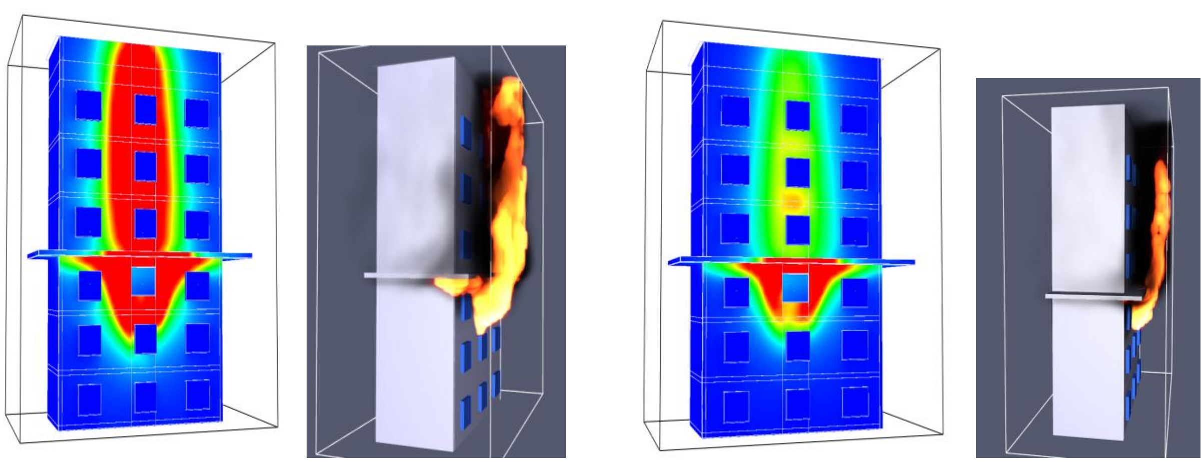


(Type 1) (Type 2)

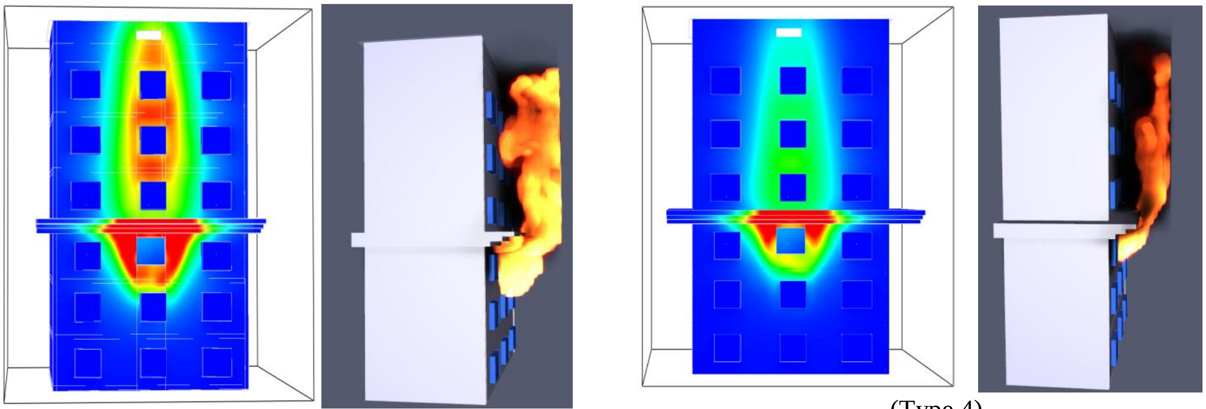
(Type 3) (Type 4)

FIGURE 4. Investigated models of facade fire-preventing eaves.

The total duration of calculations was 1200 seconds, which is due to the standard time for fire rescue units arrival in the city (10 min) according to [15], as well as additional time to deploy forces and means of fire rescue units to eliminate fire (also 10 min). According to the modeling results, the facade heating temperature distributions of the computational model are constructed. The results of modeling, as well as fire visualization are shown in Fig. 5.



(Type 1) (Type 2)



(Type 3) (Type 4)

FIGURE 5. Results of the maximum facade heating temperature distributions of the calculation models.

The modeling results revealed a regular increase in the area of facade heating for straight eaves of non- round shape, while the presence of a fire-preventing eave on the facade of a straight building does not prevent the full spread of heat during a fire, both vertically and horizontally, but significantly reduces it maximum value and increases the duration of heating the facade surface. The assumption stated in [4] is also confirmed and it shows that direct contact of turbulent heat flow from fire in the building with obstruction of non- round form increases the critical heating area of the house facade under the fire-preventing eave and above it by 30-35%.

Figure 6 shows graphs of temperature dependences above the fire floor on the duration of the fire.

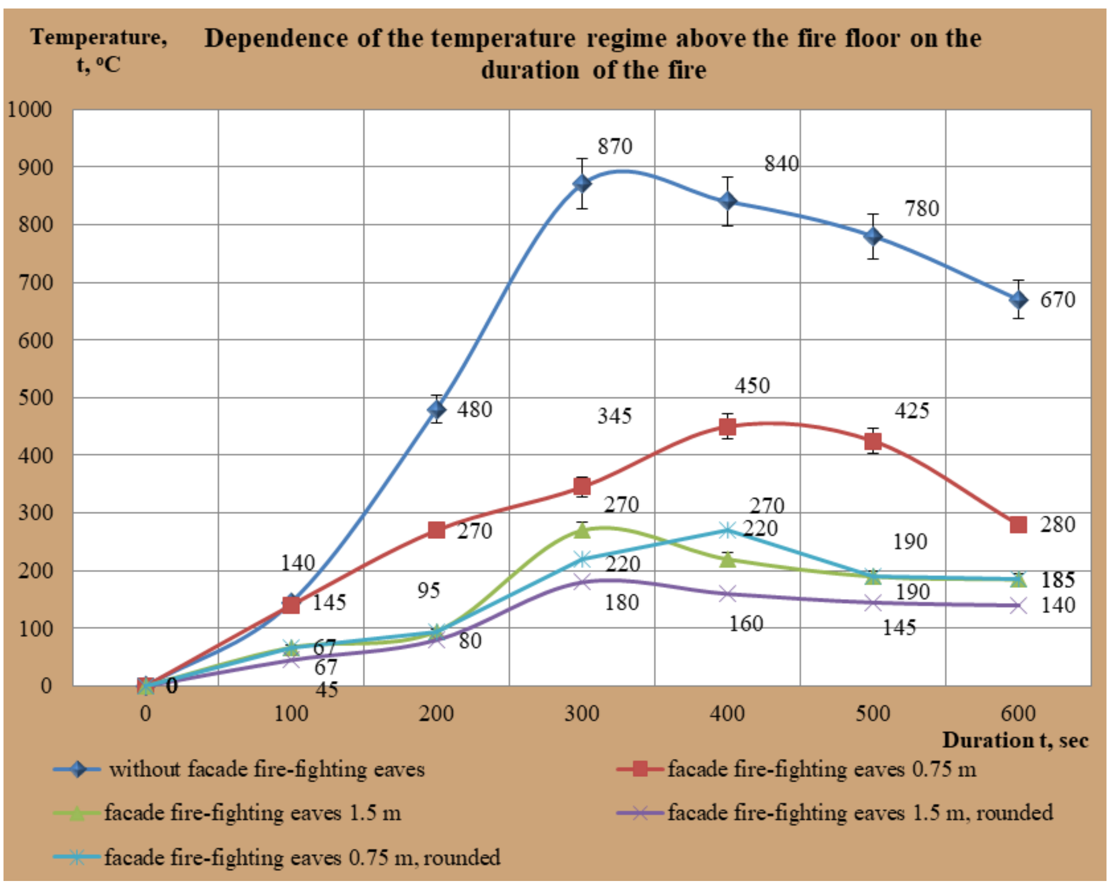


FIGURE 6. The results of the dependence of the temperature over the fire floor on the duration of the fire.

The results of this modeling demonstrate the presence of a significant influence of the shape of fire-preventing facade eaves on the effectiveness of fire prevention for vertical building structures, namely the use of round eaves is the most effective design.

CONCLUSIONS

Thus, under these modeling conditions, it was found that the presence of a fire-preventing facade eave with a protrusion of 0.75 m and 1.5 m is an effective measure that can limit the temperature of the fire at the level of the upper floor below which it arose from 870°C to 450°C and 270°C, respectively. At the same time, the straight form of a fire-preventing facade eaves increases the area of temperature distribution of heating the facade surface within 30-35% under the given models and for the data of volume-planning facade of the high-rise building. At the same time, the straight shape of the eave increases the area of temperature distribution of heating of the facade surface structure by 30-35% under these models and for the data of volume-planning facade of a high-rise building.

It was found that under these conditions, the surface temperature of the facade for the upper floor, which is located above the floor where the fire occurred in the presence of a round fire-preventing eave decreases from 270 °C (± 30 °C) to 180 °C (± 10 °C), which can significantly affect providing conditions to limit the further spread of the fire.

The study of the efficiency of heat removal from the facade and the effectiveness of fire-preventing facade eaves to prevent the spread of fire by vertical structures of high-rise buildings, as well as the derivation of efficiency coefficients depending on the shape or type may be the subject of further research, including field tests.

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