Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 55(11) (2024) 271-274
DOI: 10.22060/mej.2024.22506.7634

Numerical study of the spread of toxic and hot fire gases in a multi-story residential complex with and without sprinkler fire extinguishing system

Hamid Tajaddod, Ghassem heidarinejad *, Mohammad Safarzadeh

Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT: In this study, the effect of a water-based fire suppression system on fire control and extinguishment in a multi-story building was investigated using FDS software. The geometry consisted of a five-story building with a total of 25 units, where the fire room with heptane fuel was located on the third floor in the center of the ground floor room. Temperature parameters and species such as carbon monoxide and carbon dioxide were measured in each room, and the results were analyzed for two conditions with and without sprinklers from the start of combustion to 100 seconds. Validation showed that the numerical results of this study had an 8% relative error compared to experimental results. Additionally, in the condition without sprinklers, the temperature in the third-floor fire room reached 700 degrees Celsius within 30 seconds, but with sprinklers, extinguishment occurred in less than 20 seconds. This behavior also occurs for toxic species such as carbon monoxide and carbon dioxide, which are at risk on all floors above the fire room without sprinklers. Therefore, by considering minimum, maximum, and average values, the importance of sprinklers in extinguishing fires in the room and controlling toxic and hot gases in other rooms can be concluded.

Review History:

Received: Jun. 24, 2023
Revised: Oct. 18, 2023
Accepted: Jan. 08, 2024
Available Online: Jan. 19, 2024

Keywords:

Building Fire
FDS Software
Sprinkler Fire Extinguishing
Toxic and Hot Gases
Fire Control

1- Introduction

In the contemporary world, events such as fires are generally recognized as high-risk events with significant consequences. The construction of large buildings and various complexes has created a new challenge for fire safety, with building fires accounting for a significant portion of these types of events. Among building fires, situations where the number of floors exceeds one floor pose concerns such as providing escape routes and preventing the spread of toxic gases to upper floors. These challenges make fires on upper floors a scenario that requires more study than ever before.

To this end, studies have been conducted on the spreading and control of fires in various buildings and compartments. For example, Safarzadeh et al. [1] investigated the numerical growth and spread of fire in a one-story and a three-story building. The results showed that when the fire spreads outside the room, it can also expose upper floors to toxic and hot gases, such that the temperature in the third floor reaches 1000 Kelvin and toxic gases such as carbon dioxide and carbon monoxide also reach critical conditions. Safarzadeh et al. [2] observed in another study that even with an increase in the number of floors from 3 to 5, this risk persists and upper floors of the room on fire are exposed to toxic and hot gases.

Based on the review and analysis of previous studies, one of the gaps in these studies is the lack of investigation into the effect of the fire sprinkler system on controlling and extinguishing fires in multi-story buildings to prevent the spread of toxic and hot gases to upper floors. Therefore, in this study, first, the growth and spread of fire in the interior space of the building with a fuel source placed at the center of the room on the ground floor are investigated. In the second step, the effect of the fire sprinkler system on controlling the fire and preventing the spread of toxic gases and smoke to upper floors and adjacent areas is studied and compared.

2- Methodology

Fire behavior in an environment is a physical phenomenon and of the turbulent flow type. In the continuous phase, mass, momentum, energy, and species conservation equations need to be solved alongside the equation of state. The sprinkler spray is modeled using the Lagrangian approach. In these models, Lagrangian particles are injected into the computational domain. Particle motion and interaction between the continuous and discrete phases are determined by solving Lagrangian equations of motion.

In this study, version 6.7.6 of the open-source fire dynamics simulator software was used to simulate the fire. This software solves the Navier-Stokes equations numerically for low-speed flows and thermal flows with an emphasis on heat and smoke transfer caused by combustion. The partial

*Corresponding author's email: gheidari@modares.ac.ir

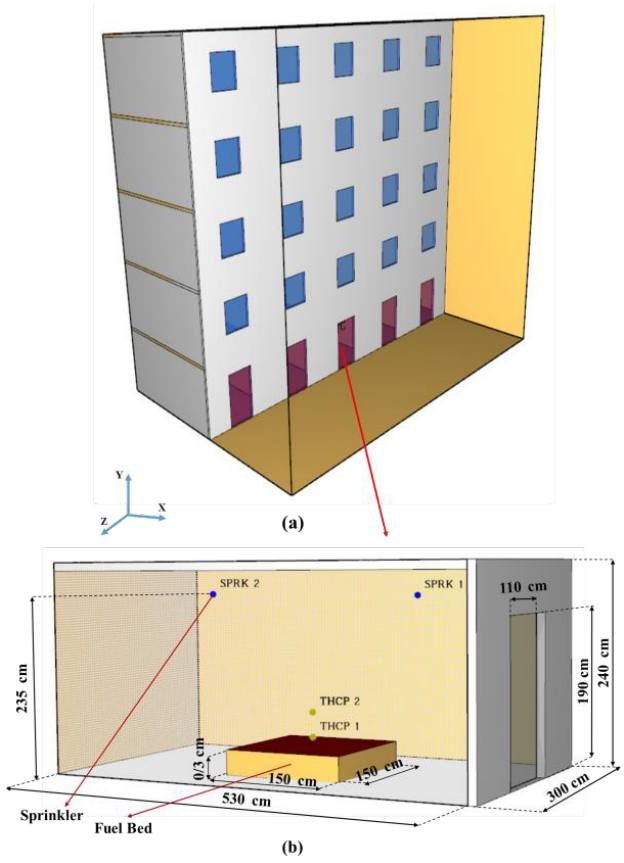

Fig. 1. Geometry of CFD domain

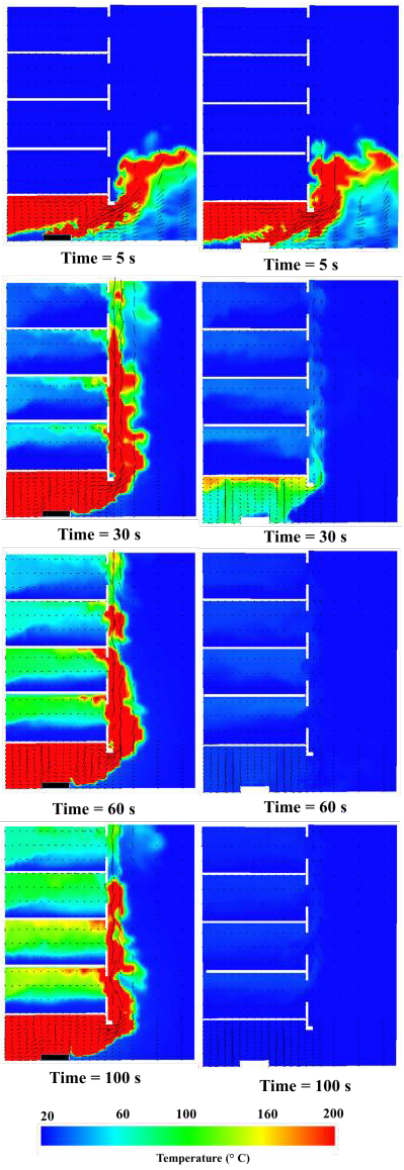

Fig. 2. Temperature contour

differential equations were solved using the second-order, time-accurate, and spatially-discretized finite difference method explicitly.

3- Result and Discussion

The study focuses on a commercial-residential building with 25 rooms, where the ground floor rooms are commercial and floors 1 to 4 are residential. The room geometry is based on the study by Li [3], which considers a single-compartment geometry and experimentally and numerically investigates the effect of a water mist fire suppression system with a nozzle on the interaction of heptane pool fire. Fuel source and other measurement parameters, including temperature sensors, species, and sprinkler fire suppression system, are located on the ground floor and in unit 3. The sprinklers will be activated after 10 seconds. The complete specifications of the room, along with equipment installation details, are shown in Figure 1.

In Figure 2, the results of hot gas dispersion in the building floors without and with sprinkler systems are shown. The results are displayed for four time intervals: initial, 30 seconds, 60 seconds, and 100 seconds. The temperature range is from 0 to 1500 degrees Celsius, but for better visualization, the range from 0 to 200 degrees Celsius is selected. In the initial state, the hot gases produced by combustion, which have a lower density than fresh air, move towards the ceiling of the room. According to the temperature contour in Figure 2, at 30 seconds, the temperature in the third room on the first floor reaches 200 degrees Celsius. At 60 seconds, more heat penetration is observed on other floors compared to previous times; thus, the temperature is about 120 degrees Celsius on the second floor and less on the third and fourth floors. This result shows that the farther the floors are from the fire room, the lower the temperature they have and the less risk they pose. As observed in the figure, the flames have also reached up to the third floor and have an advance of one meter in horizontal dimension from the front door.

In the second part of this study, to investigate and analyze the use of sprinkler fire suppression system and its extinguishing process, Figure 2 shows its results. The sprinkler fire suppression system is activated after 10 seconds. The behavior and the process of fire development are similar to the previous state, but it differ from 10 seconds onwards. Until 10 seconds after the activation of the sprinkler system, the fire is still active, which is why in Figure 2, it can be seen that although the temperature has decreased by 30 seconds and the peak heat of the fire has been controlled, a temperature of 100 degrees Celsius is still obtained at this time (although it should be noted that the temperature of the fire room is still close to 100 degrees Celsius at 30 seconds, the fire has been extinguished before this time).

4- Conclusions

The lack of investigation into the effectiveness of water-based fire suppression systems in controlling and extinguishing fires in multi-story buildings to prevent the spread of toxic and hot gases to upper floors is one of the gaps in previous studies that have been examined in this study. Based on the observed temperature and toxic species in the case without sprinklers, at 100 seconds, the temperature conditions in the third-floor room reached 700 degrees Celsius, while lower temperatures were recorded on the third and fourth floors. This result indicates that the further away the floors are from the fire room, the lower the temperature and the less risk involved. Additionally, at 100 seconds, the amount of carbon monoxide in the first and second floors was reported to be 220 and 175 ppm, respectively, while it was less than 100 ppm in the third and fourth floors. In the case with sprinklers, the fire was extinguished before 20 seconds had passed, but toxic and hot gases remained in the rooms, gradually escaping from the rooms after the fire was extinguished.

References

[1] M. Safarzadeh, G. Heidarinejad, H. Pasdarshahri, Air curtain to control smoke and fire spread in a ventilated multi-floor building, International Journal of Thermal Sciences, 159 (2021) 106612.

[2] M. Safarzadeh, G. Heidarinejad, H. Pasdarshahri, The effect of vertical and horizontal air curtain on smoke and heat control in the multi-storey building, Journal of Building Engineering, 40 (2021) 102347.

[3] J. Lee, Numerical analysis on the rapid fire suppression using a water mist nozzle in a fire compartment with a door opening, Nuclear Engineering and Technology, 51(2) (2019) 410-423.

HOW TO CITE THIS ARTICLE

H. Tajaddod, Gh. heidarinejad , M. Safarzadeh, Numerical study of the spread of toxic and hot fire gases in a multi-story residential complex with and without sprinkler fire extinguishing system, Amirkabir J. Mech Eng., 55(11) (2024) 271-274.

DOI: 10.22060/mej.2024.22506.7634