Journal of Manufacturing Engineering, December 2023, Vol. 18, Issue. 4, pp 141-144
DOI: https://doi.org/10.37255/jme.v18i4pp141-144

NUMERICAL SIMULATIONS ON VISIBILITY AND TEMPERATURE IN A CAR PARK OF A COMMERCIAL BUILDING

***Behbahani F[1], hamzei M[2], Mehrdoost Z[2] and Moghiman M[3]**

[1] Department of Mechanical Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran,
[2] Department of Mechanical Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran
[3] Department of Mechanical Engineering, Ferdowsi University, Mashhad, Iran

ABSTRACT

The study of temperature and visibility in the parking lot of the commercial complex was done using the Fire Dynamic Simulator code with various fire accidents. Specification fire of parking was obtained in different fan system conditions. The temperature and visibility of a stairwell under multiple conditions were contrasted. The values were obtained at a height of 1.6m. The results showed that temperature and visibility reached 80°C and 1 meter in the first state in the 1200s after the fire. In the second state, visibility reached 6.34m in the 1200s, 6.34 times better than in the first. The temperature also decreased to 51.11°C in the 1200s. The temperature improved by 36.19% compared to the first state. In the third state, after the 1200s, the temperature decreased to 44.72°C. In the third state, the visibility was 15.59m, which improved 15.59 times in the first state.

Keywords: *FDS; Fire accident; Temperature; Visibility; fan system.*

1. Introduction

With the urban enlargement and population growth, many large commercial or residential buildings have been built in today's advanced life. Closed car parks are used in the basement of these buildings [1]. During a fire in a closed parking lot, plenty of hot smoke is produced that must be evacuated. In addition, car exhaust contains dangerous gases such as carbon monoxide. In the parking, the air is heavily polluted by cars [2]; if a fire happens, the smoke from the fire will cause people's deaths. The purpose of fire simulation is to maintain the safety of residents to prevent casualties during a fire. In addition to heat and smoke, combustion also produces gases. The volume of hot gases in a closed space rises rapidly and fills the room [3]. In 2011, vehicle fires in tunnels with various ventilation were simulated. The simulations showed that vehicle fires caused by strong forced ventilation were 10 times more significant than natural ventilation [4]. In 2014, Zhang experimentally developed a method for predicting the temperature of smoke from fires in large spaces. It was found that by choosing the appropriate shape factor for the desired model, it is possible to predict the temperature caused by fire [5].

In 2011, three types of fire tunnels were studied experimentally. Experimental equations for flame height and shape, topmost temperature, and height of the top temperature were obtained according to the results of the desired scale [6]. In 2016, fire suppression of commercial buildings with the sprinkler system was analyzed. In the paper, different activation modes of the sprinkler were studied numerically to investigate the fire of a large commercial complex. The simulation results show that the sprinkler prevents the fire from slowing down and increases people's evacuation time [7]. A fire was simulated in a garment factory [8]. The results showed that after 6s from the start of the fire, the smoke spread on the floor and stairs and reached the upper floors, making the situation critical for the residents. In 2020, a devolatilization model was used to simulate small tunnel experiments with variable ventilation rates in unit fireboards as a fuel source. Decomposition behaviour was effectively described, and optimized values were developed numerically [9].

In 2020, a numerical analysis of the fire caused by pressure changes was performed in an air-tight enclosure with ventilation devices. The pressure in the next room becomes so high that it becomes difficult to evacuate people [10].

In 2020, smoke spread on a staircase was studied. In this study, the effect of external wind was considered. The results show that the ascent speed of the plume increases to a certain height with the wind speed [11]. In 2021, the smoke expansion system was optimized in fire scenarios using a computational fluid dynamics model [12].

**Corresponding Author - E- mail: behbahani.fatemeh652@gmail.com*

Journal of Manufacturing Engineering, December 2023, Vol. 18, Issue. 4, pp 141-144
DOI: https://doi.org/10.37255/jme.v18i4pp141-144

According to previous research, the study of visibility and temperature profiles on people's exit stairs has yet to be investigated. For this reason, the fan system's effect on the stairwells' temperature and visibility at a height of 1.6m was investigated in this research.

2. Mathematical Model

2.1 Fluid-dynamic Model

The fire simulation was done using the fire dynamics simulator code. The simulations in this article were done using the computational fluid dynamics code of FDS6.7.9. The equations are given below [13-14]:

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial}{\partial x_j}(\bar{\rho}\tilde{u}_j) = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(\bar{\rho}\tilde{u}_i) + \frac{\partial}{\partial x_j}(\bar{\rho}\tilde{u}_j\tilde{u}_i) = -\frac{\partial(\bar{P}-\bar{P_0})}{\partial x_i} + \bar{\rho} g_i \delta_{i3} + \frac{\partial}{\partial x_j}\left\{\mu\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial \tilde{u}_k}{\partial x_k}\right)\right\} + \frac{\partial \tau_{ij}}{\partial x_j} \qquad (2)$$

$$\frac{\partial}{\partial t}(\bar{\rho} C_p \tilde{T}) + \frac{\partial}{\partial x_j}(\bar{\rho} C_p \tilde{u}_j \tilde{T}) = \frac{\partial \bar{P_0}}{\partial t} + \frac{\partial}{\partial x_j}\left(k\frac{\partial \tilde{T}}{\partial x_j}\right) + \frac{\partial h_j}{\partial x_j} + \bar{q}_c + \bar{q}_r \qquad (3)$$

2.2 Numerical Setup

The parking is located in a commercial complex. The visibility and the temperature profiles in the parking fire were investigated. The parking space has dimensions of 48m✕19m ✕3m. Figure 1 shows a schematic of parking. It is essential to check the stairs because people escape during the fire. Due to the importance of the stairs, the temperature measuring devices were placed on the first and third stairs.

According to firefighting standards[14], the amount of heat released in the sample fire must be 4MW to simulate a fire in the closed parking area. Hence, according to previous research, a fire with dimensions of 1m✕1m and heat release of 4000kW/m^2 was considered in the northern of the parking.

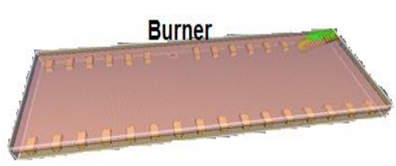

Fig. 1 The parking geometry

2.3 Grid Study

Choosing a suitable grid size is very important in getting accurate results. The ratio of the fire characteristic diameter to grid size, $D^*/\partial x$, is a measure of grid resolution. The grid size is considered between 0.1m and 0.6m. The temperature solution results were compared with each other in the 120s. The temperature is shown in Fig.2. As seen from the figure, the diagrams are almost aligned in the sizes 0.2m and 0.1m. Therefore, the solution was done for meshing with size 0.2m.

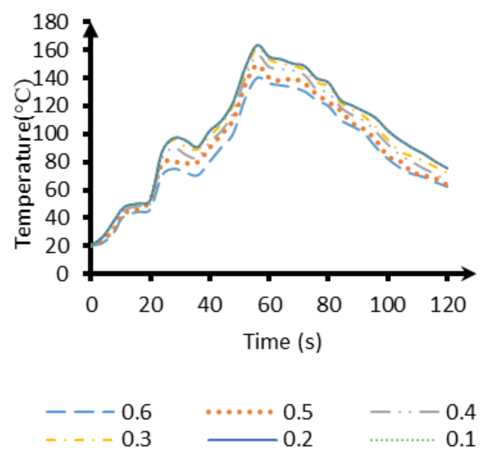

Fig. 2 Temperature profiles in different mesh sizes

3. Result

In this study, the first scenario, parking without ventilation, was considered. The second scenario evaluated the parking with a traditional ventilation system. In the last scenario, parking with a Jet fan was considered. The temperature and visibility profiles were obtained in all plans for the 1200s.

The temperature of the stairs in the parking is critical. In Fig. 5, the temperatures of the stairs are compared in different scenarios. In the first scenario, the temperature is initially 20°C. When the fire starts, this value increases to about 96°C in the 600s, then decreases to 80°C when the simulation is finished. In the second scenario, the temperature will increase to 87°C in 600s, but with the activation of the exhaust fans and supply fan, after 900s, the temperature will reach 70°C. It decreases to 51.11°C in the 1200s. In the third scenario, where the jet fan is active, in the 600s, the temperature rises to 86.8°C, and after the 900s, it drops to 74.2°C, and in the 1200s, to 44.72°C.

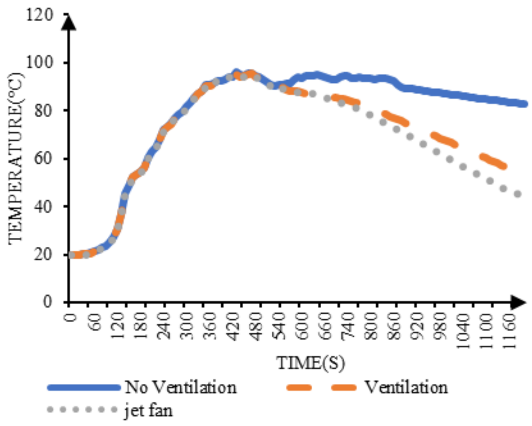

Fig. 3 Temperature profiles in three scenarios

Visibility is the distance a person can see during a fire. In Fig.4, visibility in three different scenarios is contrasted. Visibility was 30m before the fire started. With the advent of fire and the spread of smoke, this amount decreased to 1m in the 30s. A person in a parking area without ventilation does not see how to escape. In the second scenario, in the 30s, the visibility decreases to 1m, but with the activation of the fans, the visibility increases after the 550s. It reached 6.34m in the 1200s. In the third scenario, the visibility decreases to 1m, but when the jet fan is activated, it gets 15.59m in the 1200s.

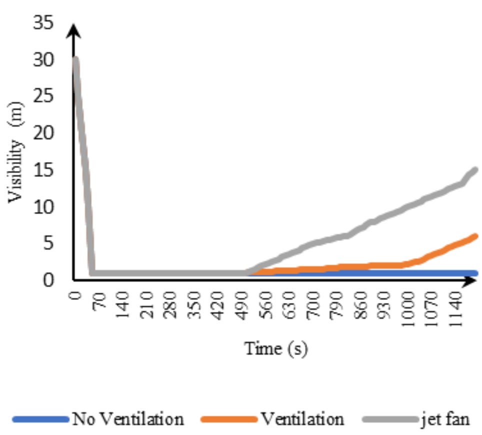

Fig. 4 Visibility profiles in three scenarios

4. Conclusion

In this study, visibility and temperature profiles in parking were investigated. Three different scenarios were defined. In the first scenario, there is no ventilation. In the second scenario, parking was provided with ventilation. In the last state, a jet fan was used for ventilation. This article aimed to investigate the effect of a ventilation system on the visibility and temperature profiles of stairwells at a height of 1.6m during the fire. In the desired space, the fire was simulated with heat release 4MW and at 1200s, visibility and temperature were compared in three scenarios. According to the results obtained, it was found that in the first scenario, before the fire, visibility was 30m. After the fire, the visibility decreased to 1m. In the second scenario, the visibility increased to 6.34m and improved 6.34 times. In the third scenario, the visibility increased to 15.59m, which was enhanced by 15.59 times compared to the first scenario. In the first scenario, the temperature was initially 20°C. After the start of the fire, the temperature increased to 96°C; it reached 80°C at the end of the fire investigation. In the second scenario, the temperature rose to 87°C, but after the 900s, it decreased to 70°C and at the 1200s, it reached 51.1°C, which improved by 36.12% compared to the first scenario. In the third scenario, using a jet fan, the temperature went 86.8°C at 600s, and after 900s, it decreased to 74.2°C; at the 1200s, it got 44.72°C compared to the first scenario, it improved by 44.1%.

References

1. *H. Park, B. J. Meacham, N. A. Dempsey, M. Goulthorpe, "Conceptual model development for holistic building fire safety performance analysis," Fire Technol., vol. 51, pp. 173–193, 2015.*

2. *W. K. Chow, C. L. Chow, "Simulating Smoke Filling in Big Halls by Computational Fluid Dynamics," Modelling and Simulation in Engineering, pp. 1-16, 2011.*

3. *X. Q. Sun, L. H. Hu, W. K. Chow, Y. Xu, F. Li, "A theoretical model to predict plume rise in shaft generated by growing compartment fire," Int J Heat Mass Transf, vol. 54, no. 4, pp. 910 – 920, 2011.*

4. *R. O. Carvel, A. N. Beard, P. W. Jowitt, "The influence of longitudinal ventilation systems on fires in tunnels," Tunnelling and Underground Space Technology, vol. 16, pp. 3–21, 2001.*

5. *G. W. Zhang, G. Q. Zhu, F. A. Yin, "Whole Process Prediction Method for Temperature Field of Fire Smoke in Large Spaces," Procedia Engineering, vol. 71, pp. 310-315, 2014.*

6. *H. Kurioka, Y. Oka, H. Satoh, O. Sugawa, "Fire properties in the near field of square resource with longitudinal ventilation in tunnels," Fire Safety Journal, vol. 38, pp. 319–40, 2003.*

7. *Y. Xin, M. Jian, S. Y.x., L. Lin, "Suppression effect of a sprinkler system on fire spread in large commercial buildings," Procedia Engineering, vol. 135, pp. 455-462, 2016.*

8. *M. A. R. Khandoker, R. J. Mou, M. A. Muntaha, M. A. Rahman, "Numerical simulation of fire in a multistoried ready-made garments factory using PyroSim," AIP Conference Proceedings, vol. 11, pp. 1-7, 2018.*

9. *X. Wang, C. Fleischmann, M. Spearpoint, "Applying the FDS pyrolysis model to predict heat release rate in small-scale forced ventilation tunnel experiments," Fire Safety Journal, vol. 102946, pp. 30491-30500, 2020.*

10. *J. Li, T. Beji, S. Brohez, B. Merci, "CFD study of fire-induced pressure variation in a mechanically-ventilated air-tight compartment," Fire Safety Journal, vol. 115, pp. 1-11, 2020.*

11. *J. Li, L. Zhu, L. Ding, L. Yu, H. Wan, "Numerical investigation of external wind effect on smoke characteristics in a stairwell," Fire Technology, vol. 56, no. 4, pp. 1681-702, 2020.*

12. *T. Baalisampang, E. Saliba, F. Salehi, V. Garaniya, L. Chen, "Optimisation of smoke extraction system in fire scenarios using CFD modelling," Process Safety and Environmental Protection, vol. 149, pp. 508-517, 2021.*

13. *J. Ji, Y. Y. Fu, C. G. Fan, Z. H. Gao, K. Y. Li, "An Experimenal Investigation on Thermal Characteristics of Sidewall Fire in Corridor-like Structures With Varying Width," Heat Mass Transfer, vol. 84, pp. 562-570, 2015.*

14. *K. B. McGrattan, G. P. Forney, J. E. Floyd, S. Hostikka, K. Prasad, "Fire dynamics simulator-user's guide," version 3, NIST IR6784, National Institute of Standards and Technology, Gaithersburg, MD, 2001.*

15. *K. B. McGrattan, H. R. Baum, R. G. Rehm, A. Hamins, G. P. Forney, J. E. Floyd, et al., "Fire dynamics simulator-technical reference guide," version 2, NIST IR6783, National Institute of Standards and Technology, Gaithersburg, MD, 2001.*

16. *Q. Sun, Y. Turkan, "A BIM-based simulation framework for fire safety management and investigation of the critical factors affecting human evacuation performance," Advanced Engineering Informatics, vol. 44, pp. 101093, 2020.*

17. *Z. Li, H. Huang, N. Li, M. L.C Zan, K. Law, "An agent-based simulator for indoor crowd evacuation considering fire impacts," Automation in Construction, vol. 120, pp. 103395, 2020.*

18. *B. Truchot, F. Fouillen, S. Collet, "An Experimental Evaluation of Toxic Gas Emissions from Vehicle Fires," Fire Safety Journal, pp. 111-118, 2018.*

.