Investigating the effects of Loung chair fire in a cinema hall using Displacement, Impingment jet and Stratum ventilation systems

Mostafa Ramezani[1], Amir Mohammad Jadidi[2*], Rouhollah Rafee[3]

[1, 2*, 3] Faculty of Mechanical Engineering, Semnan University, Semnan, Iran

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ABSTRACT

In this article, the effects of a burning a chair in a cinema hall have been investigated by using displacement, impingement jet and stratum ventilation systems. The most important results of this study by comparing among displacement ventilation, impingement jet ventilation and stratum ventilation is that displacement ventilation and impingement jet ventilation could decrease soot of fire by 31%, carbon dioxide 16% and carbon monoxide 11% better than other systems. The concentration of toxic gases from fire in all three systems is within the permissible and safe range in a way that the two systems of displacement ventilation and impingement jet ventilation recorded 6.3 ppm and 7.5 ppm for carbon monoxide respectively. In the case of carbon dioxide gas, two systems of displacement ventilation and impingement jet have decreased CO_2 to 330 ppm and 370 ppm respectively. In controlling the heat exhaust from the doors of the cinema hall, displacement ventilation and impingement jet ventilation in door 1 are 66.6% better than stratum ventilation and in door 2 the impingement jet system is 96% better than the stratum ventilation system.

KEYWORDS

Air conditioning, Fire, Pyrosim, Carbon monoxide, LES

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[*] Corresponding Author: Email: am.jadidi@semnan.ac.ir

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1. Introduction

Because humans spend a lot of time in closed spaces, these spaces will need special attention to investigate fire. Spaces such as residential building, office buildings or recreational areas and etc. are some of these cases. Humans spend most of their time in closed spaces such as apartments and offices [1]. The lack of proper thermal comfort conditions and probably in the presence of pollutants in indoor spaces, the performance of people will be reduced and therefore it effects on people's activity and moreover it increases their dissatisfaction [2,3]. In a displacement ventilation system, generally supplied-air enters from the floor and exits through the vents at the roof. Unlike mixed ventilation (MV), this system distributes the air with low velocities and at temperatures close to the indoor temperature [4]. In the stratum ventilation (SV), the air is supplied at the side walls in horizontal direction [4]. In the Impingement Jet Ventilation (IJV), an air jet with high momentum is impinges the floor vertically and a thin shear layer is formed along the floor [4].

The role of ventilation systems in controlling fires is vital. Several major fires occurred in Iran in recent years. The fires at Jolfa custom building (1976), Neishabour railway (2003) and Plasco building (2018) are the famous fires in Iran that caused high damages and casualties [5]. In each fire, the generated smoke contains large amounts of dust, fibers, vapors, and toxic gasses that can asphyxiation [6]. More than 85% of fire deaths are due to smoke asphyxiation.

According to recent studies, the importance of fire safety and energy consumption is evident. It is necessary to pay attention to the specific designs of the ventilation systems that can give better control of toxic gasses and heat exhaust during the fire. The suitable design and operation of such systems give more time to the people to escape in the event of a fire. In the previous studies, the residential buildings, tunnels, and industrial environments were investigated. However, such a study was not performed for cinema and theater halls. Also, there are not sufficient data about the effects of toxic gasses and the selection of the efficient ventilation method for reduction of their concentrations in the cinema halls. In recent study, we tried to fulfill these gaps by obtaining a useful numerical simulation results.

2. Methodology

2.1. Governing Equations

The general mass conservation and mass conservation of species equations are presented as follow [7].

$$\frac{\partial \rho}{\partial t} + \nabla . \rho \vec{u} = \dot{m}_b''' \tag{1}$$

$$\frac{\partial}{\partial t}(\rho Y_\alpha) + \nabla .(\rho Y_\alpha \vec{u}) = \nabla .(\rho D_\alpha \nabla Y_\alpha) + \dot{m}_\alpha''' \tag{2}$$

The momentum conservation equation of motion is obtained as Equation (3). Where τ_{ij} is the stress tensor for Newtonian fluids.

$$\frac{\partial}{\partial t}(\rho \vec{u}) + \nabla .(\rho \vec{u} \vec{u}) + \nabla P = \rho \vec{g} + \nabla . \tau_{ij} \tag{3}$$

The energy conservation will be obtained as equation (4) [7]. h_s is the sensible enthalpy of the fluid and ε represents the destruction terms in the energy equation. The radiation transfer equation (RTE) is written as equation (5) [7].

$$\frac{\partial}{\partial t}(\rho h_s) + \nabla .(\rho h_s \vec{u}) = \frac{DP}{Dt} + \dot{q}''' - \nabla . \dot{q}'' + \varepsilon \tag{4}$$

$$S . \nabla I_\lambda(x,s) = -\left[\kappa(x,\lambda) + \sigma_s(x,\lambda)\right] I_\lambda(x,s) + B(x,s) + \frac{\sigma_s(x,\lambda)}{4\pi} \int_{4\pi} \Phi(s,\overset{*}{s}) I_\lambda(x,\overset{*}{s}) d\overset{*}{s} \tag{5}$$

Where I is the intensity of the radiation at especial wavelength. Also the state equation of ideal gas for flows with low Mach number is considered. Using the finite difference method with second-order accuracy, Pyrosim will be able to solve the equations of mass, momentum and energy conservation over time. Variables are updated over time using the explicit second-order Rang-Kutta method. All advection terms will be discretized in the prediction stage by the upwind method and in the correction stage by the downwind method. All diffusion terms are centrally differenced.

The method of simulating turbulence in Pyrosim software is large eddy simulation (LES). This method uses a filter (spatial averaging) that can solve large eddies in the turbulent flow but is unable to directly solve smaller eddies than the size of the filter. To consider interactions between small and large scales, we need to define subscale models. In this method, the Smagorinsky model will be used to model vortices smaller than the filter size.

2.2. Geometry and Boundary Conditions

The geometry of present study related to the cinema hall in Torbat-e Heydarieh city and this hall has dimensions of 3×5×9.8 meters (height × width × length). The walls are made of brick, sand and cement, plaster and paint. There are two doors each with dimensions of 2.4×1.6 m (height × width) and 56 chairs with dimensions of 0.5×0.45×0.45 m (height × width × length), in the form of a rectangular cube inside the cinema hall. Two fresh air supply valves in the north wall and two exhaust air vents in the ceiling are installed and the size of each vent is equal to 18× 14 inches. The number of 2,020,000 computational cells has been selected due to grid independency and the time of 170 seconds has been used for the steady state solution. More details about geometry and boundary conditions can be seen in figure (1).

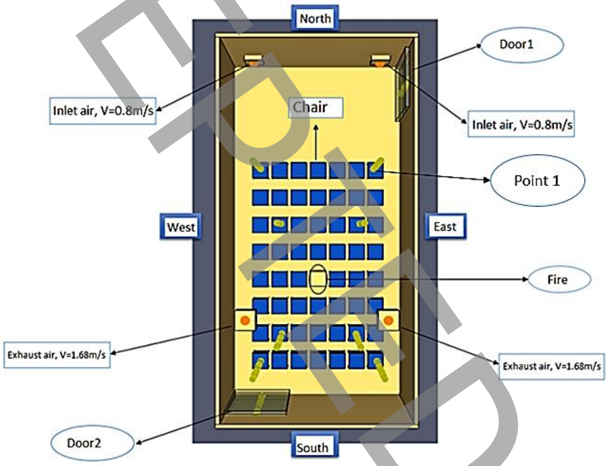

Figure 1. **the schematic of cinema hall geometry and the velocity boundary conditions**

3. Discussion and Results

Three ventilation systems including stratum ventilation (SV), displacement ventilation (DV) and impingement jet ventilation (IJV) have been considered. Figure 2 shows a comparison of fire-soot diagram versus time for the entire room space. This process (since the fire reaches its maximum heat generation rate around 40 seconds after the start of the process) should show an increase in the amount of soot around t=40 seconds. Because ventilation systems are working to remove the smoke, the closer graph's peak to 40 seconds and lower amount of soot in the peak time means better performance of a system in exhausting pollutants. Comparing the peak time of three ventilation systems to control the amount of soot in figure 2, IJV reaches to its peak time in 67 seconds, DV in 68 seconds and SV in 94 seconds. DV and IJV are 37.3% better than the SV in soot control. Finally, due to the operating time, the best performance was related to IJV system.

In figures 3, the amount of heat exhaust from the exit door number one is given versus time. This diagram shows how successful the ventilation systems were in extracting heat through the exhaust vent. According to figure 3, the best performance is related to the DV. IJV reduced the amount of heat exhaust through the door close to zero around 100 seconds after the start of the fire. In the SV case, the ventilation system could not reduce the heat passing through the door to zero. The maximum heat exhaust through door number 1 is observed in all ventilation systems precisely at the time of maximum heat release rate of the fire except for the SV (i.e. 40 seconds after the start of the fire). In the SV maximum heat transfer through the door is seen in 60 seconds after the beginning of the fire. The reason of this subject is that the heat is trapped in the hall and was not removed by exhaust vents.

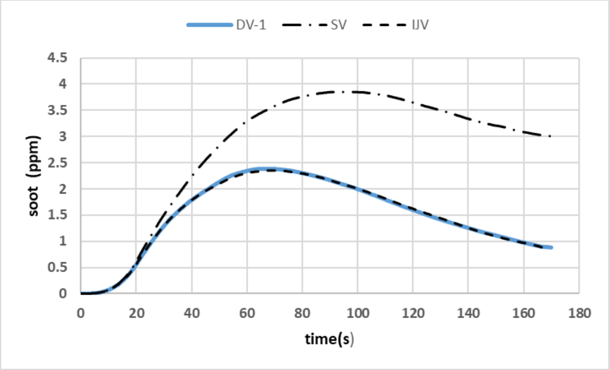

Figure 2. **Soot versus time in three different ventilation systems**

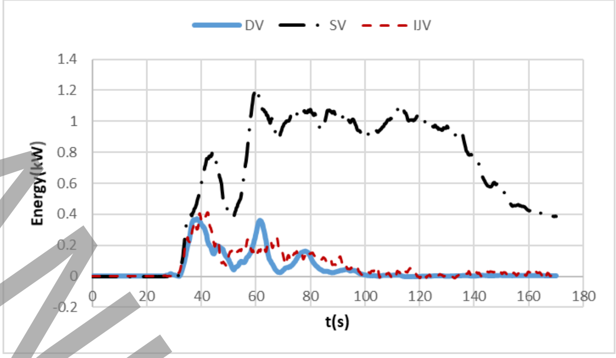

Figure 3. **Amount of heat exhaust through door 1 in three ventilation systems**

4. Conclusions

The comparison of the findings and the results showed that finally, among the DV, SV and IJV, good performance to control the fire, both in terms of contaminants and in terms of heat exhaust obtained by the DV and IJV, which has performed up to 40% in removing pollutants (Soot, CO and CO_2) and up to 96% in exhausting heat from doors. Comparing all the results of contaminants, it was observed that the level of toxic particles in the cinema hall is less than the allowable level in a small fire. It can be concluded that for the small volume fires, the need for the use of fire extinguishing systems is not necessary and a well-designed ventilation system can easily perform this

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action at the right time to remove the fire products out of the environment.

5. References

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