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Numerical Investigation of Fire inside the compartment with the effect of Ventilation

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Abstract: *The objective of the present study is to investigate the effect of ventilation in building subjected to the fire inside the compartment using CFAST software with a similar concept of CFD simulation. The effect of turbulent parameters, combustion, soot formation, thermal radiation, heat transfer, and pyrolysis of combustible solid fuel have been studied to find out the variation of temperature, the concentration of N_2, CO, CO_2 and layer height in the fire under the effect of ventilation numerically. The temperature distribution and concentrations of N_2, CO, CO_2, and O_2 to the effect of inside the compartment are increased within a fraction of time and then it will be decreased due ventilation when the door and windows are opened during the fire. Similarly, the temperature distribution and concentrations of N_2 CO, CO_2, and O_2 inside the compartment will be increased and then decreased. However, the magnitude of above parameters is low when the door and windows are opened that is due to the effect of ventilation. The upper layer temperature is found as 890 K in case of without ventilation but the upper layer temperature is decreased to 700 K with ventilation due to flue gases flow out through the opening. Also, the concentration of CO is reduced from 0.7% in volume to 0.53% in volume due to the effect of ventilation. The results show that the ventilation plays a major part in the brutality of fire in any compartment. The computer program is used to create the models relies heavily on various assumptions such as the ambient temperature, wind, humidity, and the simplicity of the furniture inside the compartments. Therefore, these results only provide a certain level of accuracy, which is acceptable for investigation in small compartments. The simulation data obtained in the study has been validated with real measured data available in literature in order to attain a more accurate result. The reproduction results are well agreed with the experimental results published in the literature in a similar type of problems.*

Keywords*: CFAST Simulation, Compartmental Fire Accidents, Transient Heat Transfer, Turbulence Model and Ventilation effect.*

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I. Introduction:

Fire products like smoke and particulate matter affect human health in serious risks of diseases such as respiratory diseases, lung damage, cardiovascular disease, cancer and even death. Therefore, fire safety design is essential to bring in a characteristic of the basic combustion reaction in fire and for the study of temperature distribution in fire. Two major types of fire processes for the safety designs are involved in the safety design. The first type is the condition in which the combustible materials are used in flaming combustion, and the second type is the materials which produce heat, smoke, toxic gasses, etc. The initial fire process includes the types of ignition materials and spreading of fire on materials; smothered the fire. The factors govern the production of dangerous products are fuel and air in fires, which is mixed in the flame. The chemical reaction is having low effect in the fire but it controls combustion's efficiency. However, the complete combustion produces more heat, less smoke, and toxic gasses. The ignition of pilot type is involved with heat loss from the flame and critical mass flow rate of volatiles. Also, oxygen from air and temperature of air in ambient conditions are involved in the study of temperature distribution. Thus, the modeling and simulation fire inside the compartment is very challenging to the researchers for using the latest technology to avoid accidental fire in compartment. The CFAST or CFD simulation technique is very suitable for solving such fire accident problems.

Ventilation has been provided for fresh air intake and smoke control in a fire as well as fire protection in buildings and installation in order to ensure a depression of fire in rooms and tunnels to supply fresh air to reduce the harmful gasses concentration. Therefore, the present study is focused on the effect of ventilation parameters for better control of fire to keep away from accidental fires.

The natural and forced ventilations are employed to control the fire from the compartment. The natural ventilation is created by natural forces which cause due to the difference in air pressure around a building. This air flow will be affected by gravitational force and pressure of air. Also, free ventilation depending upon the fireplace and operation of doors and windows, and the ventilation has been enhanced by design parameters of the compartment. The fans were used for having forced ventilation by creating air flow velocity in the compartment. A small office room of dimensions mentioned in Figure 1 is considered for modeling and simulation of fire accident in the present study. The boundary conditions employed in the simulation are walls, outflow in windows and door passage, floor and roof concrete. A critical literature review has been carried out to identify the research problem.

II. Literature Review:

He et al. [1] were investigated the ventilation limited extinction of fires in ceiling in a reduced-scale vented compartment experimentally using different fuels, such as methane, propane, N-heptane, ethanol and N-butanol, covering both gas and liquid phases. The oxygen concentration and gas temperature were shown to depend on the ventilation parameter. The species transfer control the ventilation limited self-extinction, thermal environment within the compartment has direct effect on the vent flow intensity. The fire behaviors was determined the heat transfer processes together with species transfer mechanisms in this ceiling vented compartment. Sun et al [2] were investigated the flame height and temperature profile of window ejected thermal plume from compartment fire without facade wall experimentally. This study provided the experimental data and correlations on window ejected thermal plume characteristics from compartment fire at the top level of the building without the effect of facade wall. Toe et al [3] has been carried out the experimental investigation of total length of flame jet surrounded by the ceiling and walls. The square jet flame with various heat release rates and aspect ratios are analyzed. It reveals that ceiling jet flame a half-ellipse-shape is formed, due to wall-bounded and buoyancy-controlled flame jet is striking on the roof. The ceiling-bounded jet flame and flame length of the wall is compared coefficient of proportionality with non-dimensional heat release rate. The coefficient is the function of the ceiling height. Loo et al [4] has been studied the elimination features of pool fires in a fire compartment with reduced-scale and controlled ventilation experimentally. The parameter like temperature above the flame at different heights is measured. The concentration of oxygen at floor level and ceiling, concentration of carbon monoxide, compartment pressure, and ventilation rate and fuel mass loss rate are measured. The ventilation effect is studied by varying the heights. The results show that during burning condition the fuel mass loss rates are reduced when compared to free burning conditions. The concentration of oxygen didn't change significantly and the flame extinction was about 14%. Gao et al [5] has been carried out the ventilation of building calculations in the basis of fire heat release rate inside compartment using the mass loss method. The fresh air influences and accelerates the combustion during combustion and heat release rate (HRR) influences disaster intensity. The result reveals that jet range, air change rate (ACH) and inlet velocity are affected HRR between the air supply distance of 1.5-1.8m.

Hu et al [6] has been investigated the distribution of temperature inside the compartment and fire growth for various external wind speed experimentally. The heat release rate and temperature of fire and the critical heat release rate (CHRR) of flame discharge are taken from the experiment. It is observed from the result, when speed of wind increases, upper and lower part temperature difference inside the compartment is reduced. Also, when the wind speed is higher, upper part temperature and corresponding HRR is lower. The critical total heat release rates with the continuous and intermittent flame ejection are increased first and then decreases with high wind speed. Miao and Chow [7] were investigated the influence of heat release rate (HRR) and wall heat blocking effect on the plume trajectory by both experimental and simulation methods. The result reveals that the induced pressure difference acted on the whole plume and pushed the plume towards the wall like a rigid body; the initial velocity dominated from the opening to the equilibrium point and the wall heat-blocking effect dominated in the region above the equilibrium point for attached plume. Li et al. [8] has been carried out the study on effect of tunnel area, ventilation velocity, HRR and fire from solid fuel experimentally. Tests are conducted with different tunnel widths and heights in tunnel fire. It is observed that for higher proportions with well-ventilated fire there is no influence on the HRR with tunnel width but HRR increases for a lower tunnel height. The HRR increases 25% approximately related to well ventilated solid fuel fires free burn test. HRRs values are low in free burn laboratory tests for solid fuel without proper ventilation, The HRRs approximately is same (no change) as above cases with natural ventilation. Wang et al. [9] has been studied the tunnel fire smoke spread features in semi transverse smoke extraction mode experimentally using effect of smoke deplete opening procedure. It is observed that the upstream opening provisions in tunnel fire, affects the smoke back-layering. Due to that the length of smoke back layering in dominant and smoke spread rate increases considerably due to exhaust openings directed upwards. The temperature of smoke increases above the fire and smoke exhaust increased upward due to effect of axial direction air flow. Moreover, the risk of fire increases on upstream fire for occupants and the tunnel structure.

Lu et al. [10] has been studied temperature distribution in a window of compartment with two adjacent side walls. The windows are fixed at the two sides of walls symmetrically. In window dimensions are varied to study the ventilation effect. Thermocouples are mounted in the portico wall to find the temperature variation vertically. From the results, when wall parting distance decreases temperature at a particular height increases due to the plume subjected to air entrainment is reduced due to effect of walls.

Zhang et al [11] has studied the pool fires in closed compartments experimentally. Two compartments are with volume of 0.75 m^3 and 17.55 m^3. In closed compartments the mass loss rate of fuel is low but it is high in open fire. When the local oxygen is mole fraction of 10.7 to 15.3%the fire self-distinction is occurred. The results reveal that fire elimination time is proportional to the volume of compartment. Zhang et al [12] has been carried out the study on closed compartments filled with smoke with raised fire experimentally. The compartment with interior dimensions of 3 m (L) 3 m (W) and 1.950 m (H) has been chosen to do experiments with raised fires. The data, such as concentration of oxygen, light destruction coefficient and temperature of gas showed dissimilar stratification. The interface of the stratification is considered as fuel surface level. The results show that the smoke layer is continued the filling process by wall jets, it descended to the fuel surface level but did not descend directly to the floor at the center of the compartment.

Jangi and Dlugogorsk [13] have been studied a compartment with pool fire using LES with SF (stochastic fields) method. The result is shown that pool fires can be involved some levels of premixed combustion, but not a fully non-premixed flame especially in the form of lean mixture ignition. Two mechanisms for the fire intermittency depending on the distance for the sidewall are identified which is mainly because of re-ignition, quenching and interaction between flow and sidewall. Wegrzynski [14] has been performed a study of transient characteristic of the flow of heat and mass in a fire as the basis for optimized solution for smoke exhaust. A different approach was used to optimal system design, based on the transient characteristic of the fire. The present study was performed for 9 high-temperature tests and 8 numerical analysis (CFD) of airflow in an enclosed car park during a fire, using ANSYS Fluent solver. Results of the CFD analysis show a possible gain of 25–41% of system capacity, using the same ductwork and reaching the same design goal, as contemporary smoke and heat exhaust ventilation system (SHEVS). The pressure within the ductwork and at fans is almost constant in the adaptive analysis.

Torero et al [15] has been carried out the study on defining the thermal boundary condition for protective structures in fire, Engineering Structures. The explicit design is for extreme event such as earth quake or explosion. The design data is based on either empirical or historical data. This study demonstrates an adequate level of complexity and precision for the thermal boundary conditions and input parameter is fundamental to correctly describe the response of a structure during a fire event. Ren et al. [16] were investigated the effect of fire growth in a lower-floor compartment on fire evolution and the characteristics of facade flame ejection from an upper-floor compartment experimentally. It was observed that the critical HRR of lower-floor compartment for realizing flame ejection from upper-floor compartment (type II) was lower as the HRR of the upper-floor compartment is higher. Also, it was independent of the HRR of upper-floor compartment for type-I evolution while it increased with the HRR of the upper-floor compartment for type-II evolution.

III. Summary of Literature:

From above literature review, it is obvious that there are few studies available in effect of ventilation on small compartmental accidental fire using latest technology especially the effects of ventilation parameters in either fire depression or heat released rate during combustion were not studied deeply. Further several complex studies are available in literature. However, the present study is concentrated on investigating effect of ventilation on fire accidents with forced ventilation using CFAST.

1. Numerical Model:

In present study, the effect of ventilation on compartmental fire has been studied numerically. The fire inside the compartments is considered as three dimensional, transient, turbulent and compressible. The k–ε turbulent model is used to investigate the turbulent flow characteristics in the compartmental fire.

2.1 Governing Equations

The governing equations used for the present study in Cartesian coordinates are [17]:

1. **Mass conservation equation**:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \qquad (1)$$

2. **Momentum conservation equation**

X momentum conservation equation:

$$\frac{\partial}{\partial t}\left(\rho u_x\right)+\frac{\partial}{\partial x}\left(\rho u_x u_x\right)+\frac{\partial}{\partial y}\left(\rho u_y u_x\right)+\frac{\partial}{\partial z}\left(\rho u_z u_x\right)=-\frac{\partial p}{\partial x}+\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+\rho B_x \qquad (2)$$

Y momentum conservation equation:

$$\frac{\partial}{\partial t}\left(\rho u_y\right)+\frac{\partial}{\partial x}\left(\rho u_x u_y\right)+\frac{\partial}{\partial y}\left(\rho u_y u_y\right)+\frac{\partial}{\partial z}\left(\rho u_z u_y\right)=-\frac{\partial p}{\partial y}+\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{zy}}{\partial z}+\rho B_y \qquad (3)$$

Z momentum conservation equation:

$$\frac{\partial}{\partial t}\left(\rho u_z\right)+\frac{\partial}{\partial x}\left(\rho u_x u_z\right)+\frac{\partial}{\partial y}\left(\rho u_y u_z\right)+\frac{\partial}{\partial z}\left(\rho u_z u_z\right)=-\frac{\partial p}{\partial z}+\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}+\rho B_z \qquad (4)$$

3. **Energy conservation equation**

$$\frac{\partial}{\partial t}\left(\rho h\right)+\frac{\partial}{\partial x_j}\left(\rho u_j h\right)=\frac{\partial p}{\partial t}+\frac{\partial}{\partial x_j}\left(\frac{\lambda}{c_p}\frac{\partial h}{\partial x_j}-\dot{q}^{''R}\right) \qquad (5)$$

where 'h' = static enthalpy of the mixture and

$h_{total}=c_p T+\sum Y_\alpha H_r$ where H_r= Component heat of reaction, λ is the thermal conductivity and $\dot{q}^{''R}$ represents the net heat flux due to thermal radiation.

4. **Species conservation equation**

$$\frac{\partial}{\partial t}\left(\rho Y_\alpha\right)+\frac{\partial}{\partial x_j}\left(\rho u_j Y_\alpha\right)=\frac{\partial}{\partial x_j}\left(\rho D\frac{\partial Y_\alpha}{\partial x_j}\right)+S_\alpha \qquad (6)$$

where S_α = Net change of α from production and consumption in the control volume.

5. $k-\varepsilon$ **turbulence model**

The **turbulent viscosity** is given as $\mu_t=C_\mu\bar{\rho}\frac{\tilde{k}^2}{\tilde{\varepsilon}}$, where, $\tilde{k}$ is the Favre averaged turbulent kinetic energy and $\tilde{\varepsilon}$ = Favre averaged viscous dissipation rate of turbulent kinetic energy.

ε = kinetic energy to heat thermal energy, C_μ = 0.09.

The **turbulent kinetic energy equation** is given as:

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{k}\right)+\bar{u}_i\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{k}\right)=\frac{\partial}{\partial x_i}\left[\left(\frac{\mu_t}{\sigma_k}+\mu\right)\frac{\partial\tilde{k}}{\partial x_i}\right]+\mu_t\left(\frac{\partial\tilde{u}_i}{\partial x_j}+\frac{\partial\tilde{u}_j}{\partial x_i}\right)\frac{\partial\tilde{u}_i}{\partial x_j}-\beta g\frac{\mu_t}{\sigma_t}\frac{\partial\tilde{T}}{\partial x_i}-\bar{\rho}\tilde{\varepsilon} \qquad (7)$$

where σ_k is the turbulent Prandtl number for k, $\beta=-\frac{1}{\bar{\rho}}\frac{\partial\bar{\rho}}{\partial\tilde{T}}$ = thermal coefficient of expansion.

Dissipation rate of turbulent kinetic energy is given as:

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{\varepsilon}\right)+\bar{u}_i\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{\varepsilon}\right)=\frac{\partial}{\partial x_i}\left[\left(\frac{\mu_t}{\sigma_\varepsilon}+\mu\right)\frac{\partial\tilde{k}}{\partial x_i}\right]+C_{\varepsilon 1}\frac{\tilde{\varepsilon}}{\tilde{k}}\left(G_K+G_B\right)\left(1+C_{\varepsilon 3}R_f\right)-C_{\varepsilon 2}\bar{\rho}\frac{\tilde{\varepsilon}^2}{\tilde{k}} \qquad (8)$$

where σ_ε = Turbulent Prandtl number turbulent kinetic energy ε,

$C_{\varepsilon 1}$, $C_{\varepsilon 2}$ and $C_{\varepsilon 3}$ = empirical constants. $G_K=\mu_t\left(\frac{\partial\tilde{u}_i}{\partial x_j}+\frac{\partial\tilde{u}_j}{\partial x_i}\right)\frac{\partial\tilde{u}_i}{\partial x_j}$ = shear stress term, $G_B=\beta g\frac{\mu_t}{\sigma_t}\frac{\partial\tilde{T}}{\partial x_i}$ = Buoyancy term and $R_f=-\frac{G_B}{G_K}$ = Flux Richardson number.

The values of constants employed in standard $k-\varepsilon$ model are

C_μ = 0.09, $C_{\varepsilon 1}$ = 1.44, $C_{\varepsilon 2}$ = 1.92, $C_{\varepsilon 3}$ = 0.8, σ_k = 1.00 and σ_ε = 1.30.

A system of differential equations is used to model pressure, layer height and temperatures create an initial value problem in CFAST simulation. The equations based on the principles of law of conservation of mass and energy using an ideal gas law as an equation of state to relate temperature and density. The pressure (at the floor), upper layer volume, and layer temperatures due to the net gain or loss of mass and energy in these layers were evaluated on the basis of time. In CFAST, temperature can be approximated for the air by a representative average value. Though it is equivalent mathematically, numerical solution differs than formulation by approximation. The exchange of mass and energy from fire plumes by natural and forced ventilation, convective and radioactive heat transfer. Mass exchange happens in vents and heat exchange inside the room. The heat exchange happens inside room and entrainment of mass and heat from the lower to upper layer of the room and walls are heating up due to convection heat transfer from fire plumes. Momentum exchange between zones in adjacent compartments is accounted in terms of horizontal or vents flow equations (Bernoulli's law).

A standard room of size 10mx5mx3m has a doorway with dimensions of 1.1 m x 1.95 m, and two windows are each 1.05 m x 1.5 m. Both the walls and ceiling is constructed with Gypsum Board (5/8 inch). Each room has a single sprinkler on the ceiling in room Centre. A schematic diagram of the compartment used for modeling and simulation in this study is shown in Figure 1.

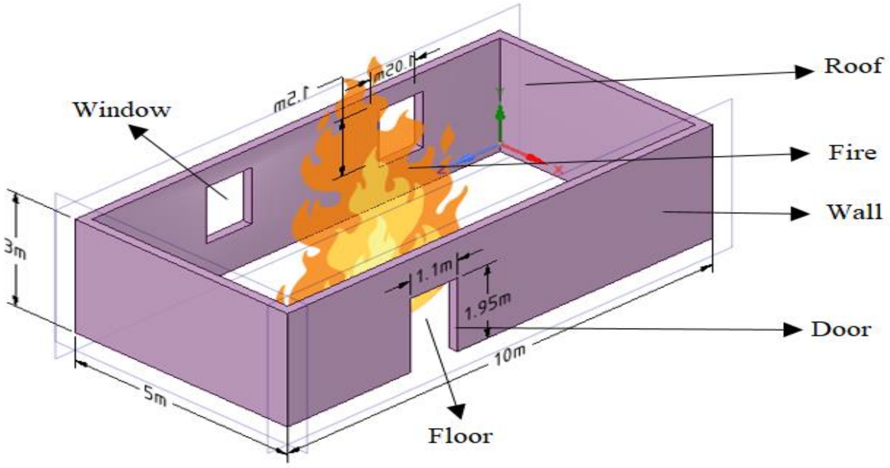
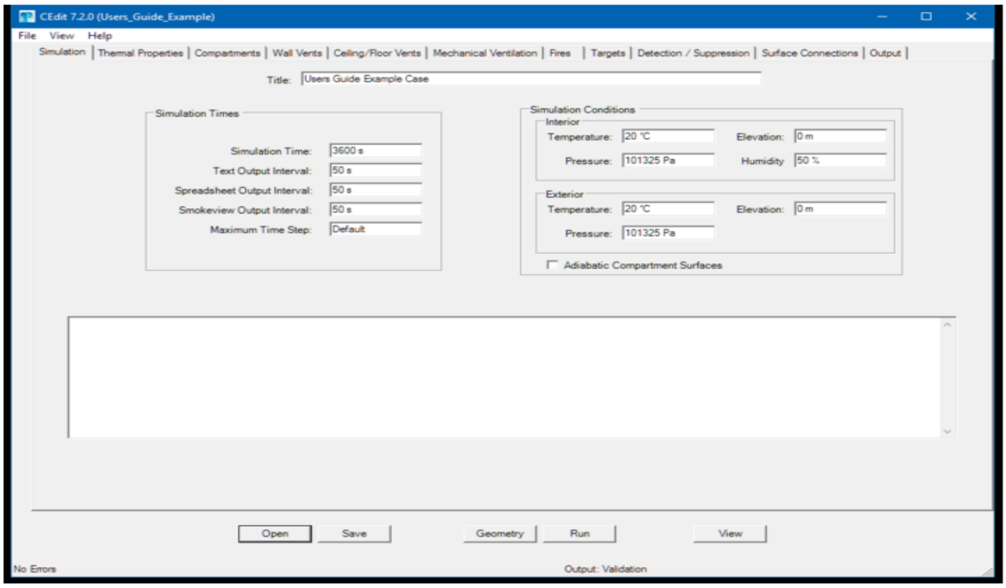


Figure 1 Computational domain and boundary conditions employed

The present study has been carried out with and without the effect of ventilation on temperature distribution and combustion of fire inside compartments. Boundary conditions employed are two windows opened and closed, one door opened and closed and remaining portions are considered as adiabatic wall. The standard fire properties are considered as input data in CFAST.

The input parameters are given via tabs near the top of the CEdit screen, as shown in Figure 2



Title: Users Guide Example Case

Simulation Times
Simulation Time: 3600 s
Text Output Interval: 50 s
Spreadsheet Output Interval: 50 s
Smokeview Output Interval: 50 s
Maximum Time Step: Default

Simulation Conditions
Interior
Temperature: 20 °C
Elevation: 0 m
Pressure: 101325 Pa
Humidity 50 %
Exterior
Temperature: 20 °C
Elevation: 0 m
Pressure: 101325 Pa
☐ Adiabatic Compartment Surfaces

Figure 2 Primary CFAST Input Page

2.2 CFAST Simulation:

CFAST software is suitable for analyzing multi compartment environment and building structure subjected to fire. But it is used for single compartment fire simulation in the present study. The following input parameters have been defined in the CFAST software for simulation.

- Simulation Environment
- Thermal Properties
- Compartments
- Wall Vents
- Ceiling/Floor
- Mechanical Ventilation
- Fires/heat release rate
- Targets
- Detection / Suppression
- Surface Connections
- Visualizations

A fire has been specified with heat release rate per second in CFAST software. The mass loss rate of fuel has been calculated from heat production of combustion and the combustion products are evaluated using special processes. When the oxygen limit is reaching the heat release rate [HRR] and combustion products goes to zero but it is compensated by unburnt fuel gas. It is calculated from zone walls until the oxygen content is significant for high temperature to complete combustion. The fires have been ignited for particular time when reaches a target temperature or heat gain. The smoke and gases combustion products and temperatures are evaluated based on time required.

The combustion model is defined by the following one-step reaction:

$$C_{nC}H_{nH}O_{nO}N_{nN}Cl_{nCl} + V_{o2}O_2 \longrightarrow V_{Co2}\,CO_2 + V_{H2O}H_2O + V_{CO}CO + V_S\,\text{Soot} + V_{HCl}HCl + V_{HCN}\,HCN$$

The nitrogen and chlorine in the fuel are converted to HCN and HCl in above chemical equation. The oxygen level has been decreased for controlling the burning rate. The unburnt fuel gas generated in the combustion due to lower oxygen depleted the compartment.

2. **Validation of numerical results with experimental data available in literature**:

The temperature distribution and Oxygen concentration obtained in numerical simulations are validated with experimental data available in literature [18]. The present simulation results are well agreed with the measured data available in the literature as shown in Figures 3 and 4.

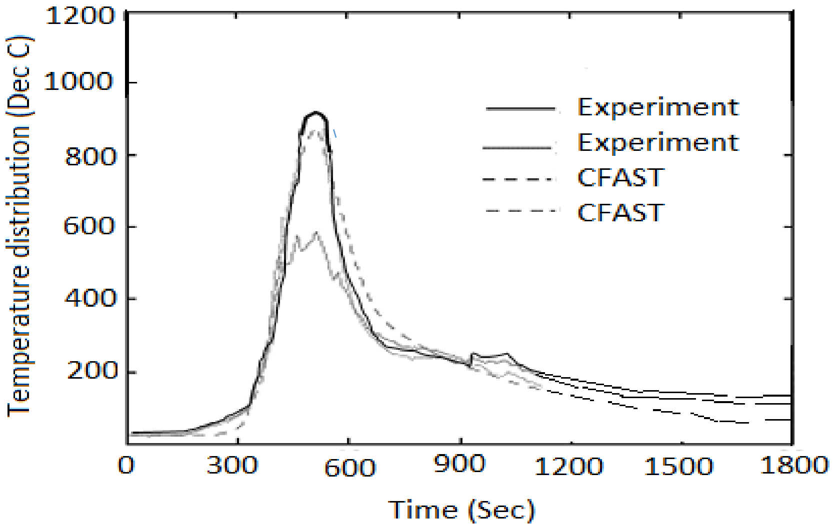


Figure 3 Comparison of temperature distribution [18]

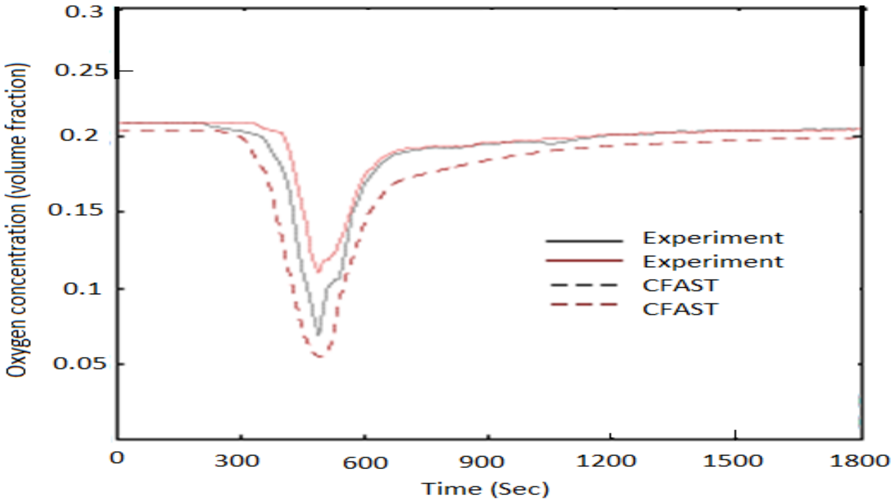


Figure 4 Comparison of Oxygen concentrations [18]

IV. Results and Discussions

The investigation of a fire in a compartment has been carried out numerically. The ventilation conditions and fuel loads are varied for the simulation. CFAST modeling and simulation program is used to investigate fire features. CFAST model provides a zone modeling capability that is appropriate for this investigation because the fire occurred in compartment, which can be easily divided into control volumes or zones. The use of CFAST is also cheaper and faster than a CFD model, and in this case, the zone model method is able to provide reasonably accurate results.

4.1 Compartmental fire without Ventilation (Door and windows closed)

Figure 5 illustrates the Nitrogen concentration variation with the time in the fire. The result shows that the nitrogen concentration for first 300 seconds is 78%in volume due to fire developing then it is decreased to 68% in volume from 300 to 500 seconds because of mixing and turbulence and then it is increased to 76% in volume from 500 to 700 seconds then it became constant due to stability of fire. The distribution of plumes inside the compartment is balanced after 700 seconds. Thus, concentration of nitrogen regains its original concentration due to the mixing of smoke with fire inside the compartment without ventilation. The nitrogen concentration inside the compartment is low in case of compartmental fire due to ventilation effect.

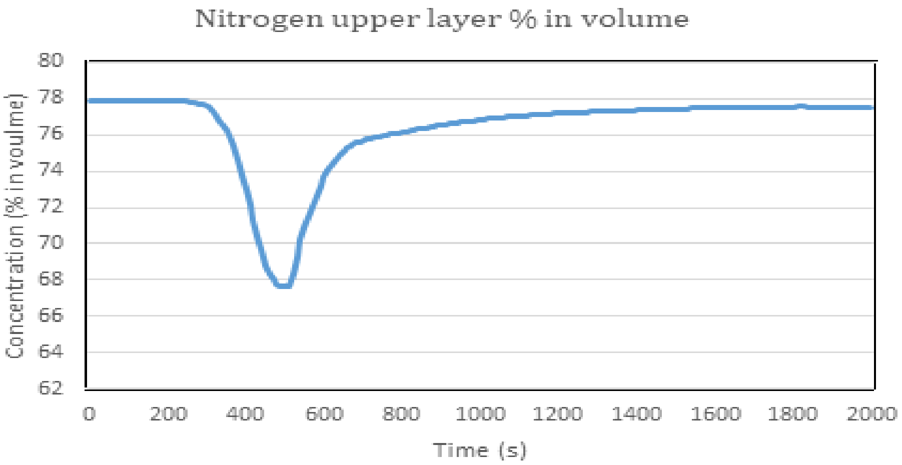


Figure 5 Variation of nitrogen concentration inside the compartment with time

Figure 6 shows the variation of layer height with time inside the compartment. It is observed that the layer height inside the compartment is 2.3 m till 200 seconds then it decreases to 1m and then it becomes unstable and increased to 2 m due to buoyancy near the wall and turbulence in the fire. The fire plume is disturbed by the smoke and species spreading inside the compartment due to lack of ventilation. However, the layer height gets established towards ceiling of the compartment after 2000 seconds. The layer height in the compartment is high in case of compartmental fire due to ventilation effect.

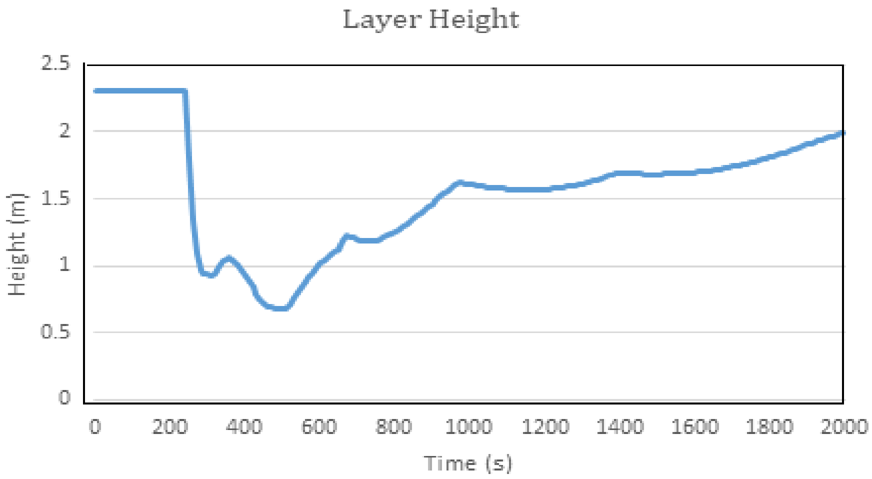


Figure 6 Variation of layer height inside the compartment with time

4.2 Compartmental fire with ventilation (Door and windows opened)

Figure 7 shows the variation of oxygen concentration with time inside the compartment. The results depict that the oxygen concentration is zero up to 200 seconds then it is increased to 3 between 200 to 300 seconds due to the mixing of oxygen with inside air and outside air to enhance the combustion. After combustion starts, it is decreased to 0.5 kg at 500 seconds due completion ventilation of hot gases from the compartment through door and windows. Then it will become unstable and increases to 2 kg due to turbulence in the fire, entrainment and mixing of outside air into the compartment. The oxygen concentration inside the compartment is high in case of compartmental fire due to ventilation effect.

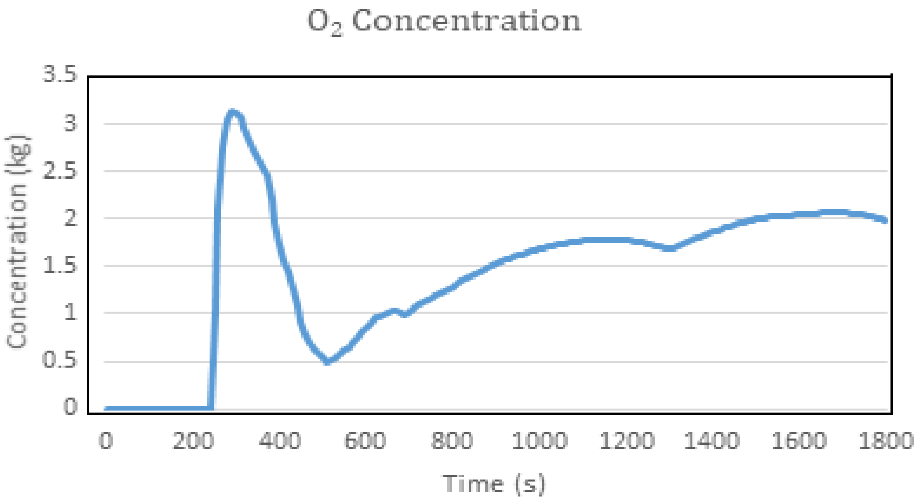


Figure 7 Variation of Oxygen concentration inside the compartment with time

Figure 8 illustrates the nitrogen concentration variation with time inside the compartment. It is observed that the nitrogen concentration is constant 78% in volume till for first 300 seconds then it started to decrease for 70% in volume from 300 to 500 seconds due to combustion, turbulence and ventilation of air from the compartment. After that it again increased to 78% in volume between 570 to 1800 seconds due to the mixing of outside air into the compartment and ventilation effect. The nitrogen concentration become stable after combustion and circulation of air and flumes inside and outside the compartment. The nitrogen concentration inside the compartment is low in case of compartmental fire due to ventilation effect.

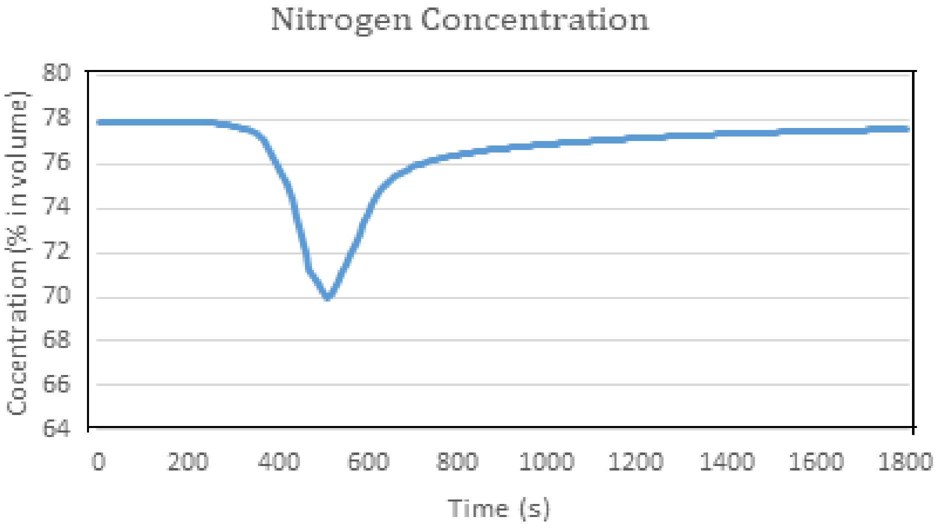


Figure 8 Variation of Nitrogen concentration inside the compartment with time

Figure 9 shows the variation of carbon dioxide concentration with time inside the compartment. It depicts that the concentration is zero till 400 seconds because the combustion delay and then it is increased to 6% in volume due to the effect of combustion and growth of the fire as well as the mutual entrainment and ventilation of flue gases and air from atmosphere through door and windows. Then it is decreased to 1% in volume after 600 seconds due to combustion and the effect of ventilation. The carbon dioxide concentration in the compartment is high in case of compartmental fire due to ventilation effect.

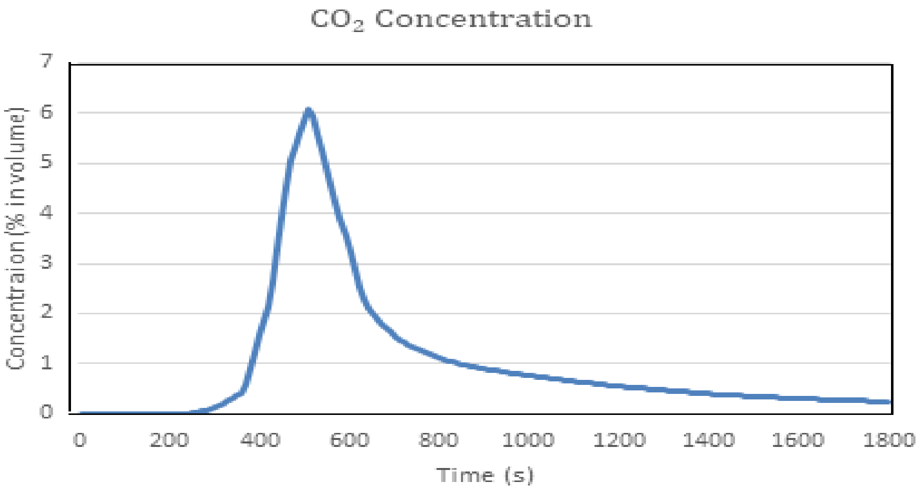


Figure 9 Variation of Carbon dioxide concentration inside the compartment with time

Figure 10 shows the variation of layer height inside the compartment with time. It is observed that the layer height is constant 2.4 m up to 250 seconds then it will be decreased to 0.9m due to the effect of ventilation through windows and door. Then the layer height is increasing unsteady to a layer height of 1.3 m due to the development of turbulence in fire which will disturb the fire and also the layer height become constant because of soothing in the fire. The layer height in the compartment is high in case of compartmental fire due to ventilation effect.

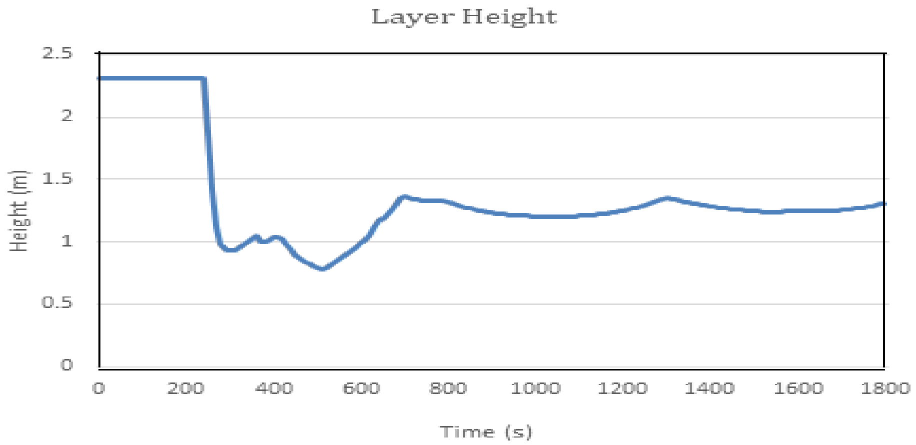


Figure 10 Variation of Layer height inside the compartment with time

4.3Comparison of parameters for effect of ventilation

The results of upper layer temperature distribution and concentrations of CO in combustion products of fire are shown in Figures 11 and 12. The result shows the effects of ventilation in the compartment clearly.

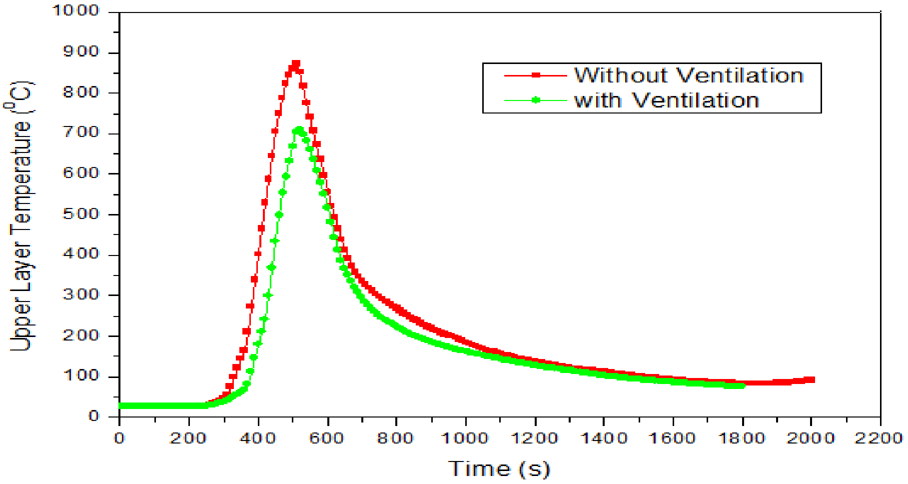


Figure 11 Variation of upper layer temperature with and without ventilation

The temperature and CO concentration increase with time and then it will be decreased due to the effect of ventilation when the door and windows are opened during the fire. However, the magnitude of the temperature distribution and concentrations of CO are higher without ventilation than that of with ventilation. The upper layer temperature and CO concentration are observed as 890 K and 0.7% in volume in case of without ventilation but the upper layer temperature and CO concentration is decreased to 700 K is 0.53% in volume in case of with ventilation.

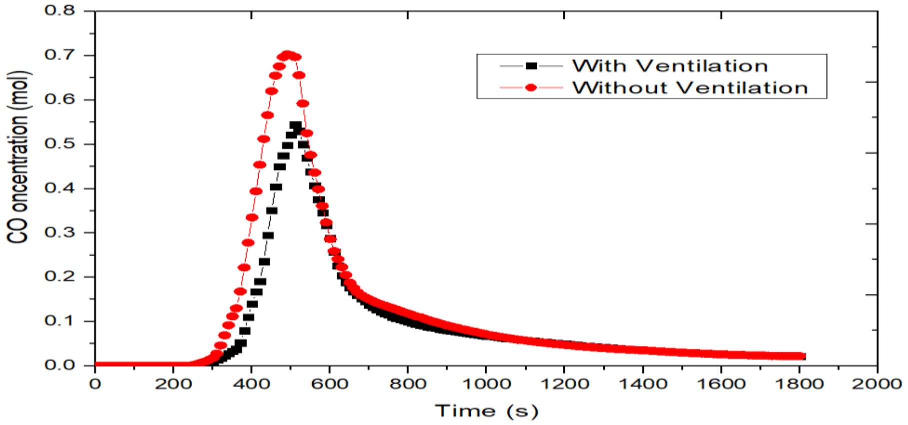


Figure 12 Variation CO concentration with and without ventilation

The temperature distribution inside the compartment remains constant 35 ^{0}C for the first 400 seconds due to delay of combustion then it has started to increase at 400 seconds and reached 700^{0}C due to the diffusion of heat inside the compartment. Then the temperature decreased to 100^{0}C due to ventilation effect that is heat transfer taken place through the door, windows by the mode of convection and walls and ceiling by conduction. But the maximum temperature of 890 ^{0}C is obtained at 500 seconds in case of without ventilation.

The carbon monoxide concentration variation inside the compartment time is constant up to 300 seconds then it is increased to 0.7% in volume and the decreased to 0.1% in volume after 500 seconds due to insufficient oxygen inside the compartment or incomplete combustion in case of without ventilation. But the concentration is constant till 400 seconds then it increased to 0.53% in volume and again decreased to 0.01% in volume after 550 seconds due to ventilation and circulation of air which helps to complete the combustion.

V. Conclusion:

In the present study, the magnitude of temperature distribution and concentrations of N_2 CO, CO_2, and O_2have been investigated numerically. The present simulation results are well agreed with the measured data available in the literature. The Effect of throttling of airflow in the windows due to a rapid expansion of air flowing over fire in the compartment has been analyzed. From the results it is observed that the temperature distribution and concentrations of N_2 CO, CO_2, and O_2inside the compartment are increased with time and then it is decreased due to the effect of ventilation when the door and windows are opened during the fire. But in case of without ventilation, the magnitude of the temperature distribution and concentrations of N_2 CO, CO_2, and $O_2$are higher when the doors and windows are closed that is due of lack of ventilation. For an instance, the upper layer temperature is 890 K and CO concentration is 0.7% in volume in case of without ventilation but the upper layer temperature is decreased to 700 K and CO concentration is 0.53% in volume in case of with ventilation. Also the pressure losses take place due to viscous effect in the fire. The wall surface temperatures increase at downstream of the fire due to impact of air flow. Different modes of heat transfer take place in association with fire. Thus the effect of ventilation plays a vital role for accidental fire inside the compartment for safety or protection.

Recommendations:

The fire modeling, reproduction, and validation using experimental measurements of combustion products can be done using latest developed CFD tool and virtual reality software. The evacuation simulators can be used for visualization processes during the complexities of fire studies. This study can be done by using advanced tool to investigate in more details which will reduce the cost and it will improve the operator skills for experimental study.

Nomenclature

c_p - specific heat capacity [J kg^{-1} K^{-1}]	T_0 - ambient temperature [K]
d_j - jet width [m]	T - temperature [K]
g - local acceleration due to gravity [m s^{-2}]	u_x, $v_x w_x$-velocity components in x,y,z directions [m s^{-1}]
k - turbulent kinetic energy [m^2/s^2]	u_0 - jet centerline velocity [m s^{-1}]
k_t - turbulent thermal conductivity [w m^{-1} K]	x, y - space co-ordinates [m]
p - pressure [N m^{-2}]	**Greek symbols**
Pr - Prantdl number [ν/α]	β - thermal expansion coefficient [K^{-1}]
Re - Reynolds number [$u_0 d_j$ /ν]	ρ - density of air [kg m^{-3}]
t - time [s]	ε - rate of turbulence dissipation [m^2 s^{-3}]
T_j- jet inlet temperature [K]	$ν_t$ - kinematic viscosity [m^2 s^{-1}]

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