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Application of Fire Dynamics Simulator in Warehouse Fires: A Case Study

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ABSTRACT: *In the case study presented in this paper, fire dynamics of a warehouse stock room containing papers and books in racks is predicted using computational fluid dynamics (CFD) technique which provides estimation for propagation of fire and its dynamics. That is why it is more pertinent for the study of plume and smoke spread behavior to be carried out. This paper covers the research area which aims to reduce the fire hazards by anticipating the movement of smoke computationally in real-life conditions. Accordingly, evacuation plans can be prepared to avoid any loss to human life by predicting the direction of smoke and its density. In the assessment various factors were considered such as the location of fire, windows, doors and quantity of burning fuel. Key findings and noteworthy conclusions were recorded.*

Keywords: Fire safety assessment; Fire dynamic simulator, fire dynamics , smokeview

1. INTRODUCTION

A fire safety assessment is an structured and methodological analysis of a workplace, storage area & premises , the activities carried out on regular basis and the likelihood that a fire could initiate and cause damage to those in and around the specific area. The objective of the fire safety assessment is to identify and recognize the potential fire hazard at or near the working area, to prepare strategies and arrangements to ensure safety of people in case of fire break out, to bring out the flaws and imperfections of current fire protection system implemented in the workplace etc.

Statistically, of all the deaths in fires, deaths because of suffocation with smoke, fumes and toxic gases are significant. Few places where smoke control and its path prediction play a vital role includes Colleges, Shopping malls, hotels, industries, warehouse etc.

Fire Dynamics Simulator (FDS), is a computational fluid dynamics (CFD) model of fire-driven fluid flow.[1] FDS is driven by LES (large eddy simulation) and works on low speed thermal driven model. It solves Navier-stokes equation to derive result from input data. Smokeview is a graphical interface that visualizes the input FDS file and is used to display the results of an FDS simulation. .[1] FDS has been developed in order to evaluate practical problems related to fire in fire protection engineering, while simultaneously providing assessment tool to study fundamental fire dynamics and combustion chemistry. FDS is a computer program engineered to solve equation and physics that recount the advancement of fire and its effect. Smoke view is a graphical interface program that reads out the FDS output files and produces visualization of data from FDS file on the computer screen. PyroSim and BlenderFDS are examples of programs used to generate the input file for FDS. They uses graphical UI to create an input file and alongside aids to run the file via smokeview.

Huo et al. [6] used FDS to simulate the typical ventilation in an air-conditioned office. Zhang et al. [7] assessed the exactness of FDS by using the heat flux and flame heights of flame for a single burning item tests. Smardz [8] tested the exactness of FDS envisage for smoke spreading from a small compartment into an adjacent larger space.

The main purpose of the current work is to foresee the scenarios of smoke circulation and it's propagation in the warehouse to put forward simple control measures to diminish smoke hazards. This objective with no trouble can be adapted to further large buildings and structures.

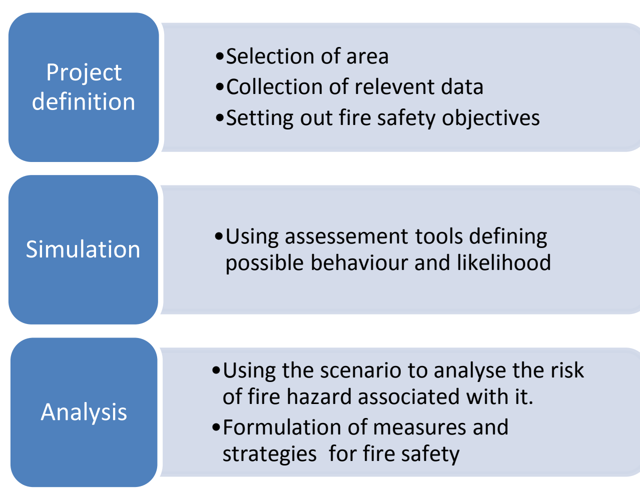

Fig. 1 Methodology used

2. DESCRIPTION OF THE MODEL

The stack room of warehouse is selected as case study for software analysis and fire risk modelling. In warehouse stack room there are lots of combustibles which can cause and be the source of fire accident in room. This compartmental fire is thus taken as the possible scenario. It is assumed that fire starts with an electrical malfunction causing nearby rack lit up. The rack is kept at a distance of only 14 cm from switch board and wire connection, thus the books in vicinity catches the fire and thus may lead to flashover.

For fire load calculation reference is taken equivalent to the book of dimension about 29.2x23.4x5.1 cm (assumed) and weight about 2.177 kg.

A total of 14 racks are there in one stack-room. Each rack can hold 4x6x2x14 number of the books. Thus one rack can hold about 672 books and total stack can hold about 9408 books overall. By this Fire load is calculated and it is about 1462.94 kg per rack. Therefore the dimension of the fuel source is about 2.352 m3 per rack. It is assumed that the rack to be packed with books.

Table 1 Dimensions of room, window and door

Particulars	Dimensions
Room	19.34 x19.09 x 3.6 (m)
Window (18 windows in each stack room)	1.8 x 1.8 (m)
Door (assumed shut)	1.8 x 2.5 (m)

For this project, human based functions are neglected from the objectives concerning discrete events and only the structural scenarios are taken into account. The fire safety measures adopted are as follows.

Proper ventilation system i.e. spacious room, windows at interval.

- Sprinkler system inside room.
- Mechanical venting system
- Windows sill procurement.
- First aid firefighting tools.

Figure 2 shows a two-dimensional view of the compartments as viewed in PyroSim Software whereas Figure 3 shows a three dimensional view of the compartment.

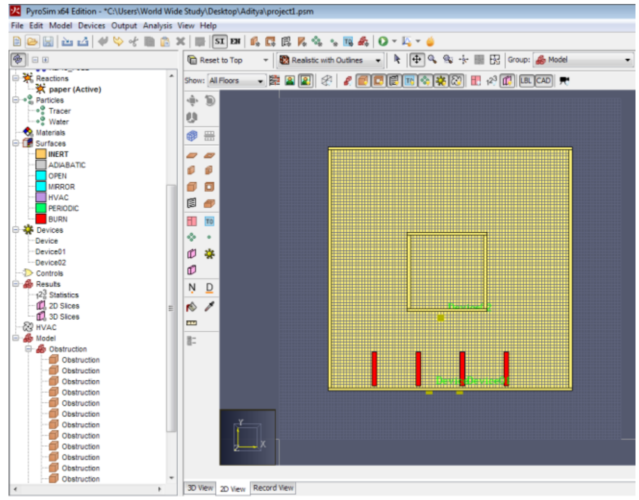

Figure 2: Two dimensional view of compartments

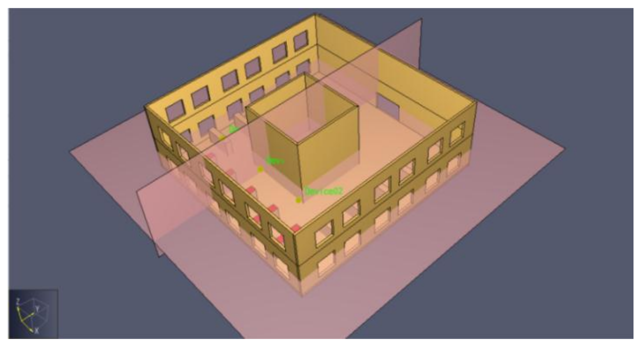

Fig 3. Warehouse modelling

3. SIMULATION & RESULT

Initially the warehouse structure is modeled (fig 2) in pyrosim graphical user interface for the Fire Dynamics Simulator (FDS) using the parameters shown in the Table1.

With the help of ground plan of the warehouse walls were created using the Draw a Room tool. Then using New Room Properties in 2D view mode, walls were created using the dimensions shown in Table 1 with suitable values of wall colors and transparency.

As each wall represents a 3D obstruction in fire dynamic simulation, adopting this method aided to avoid the manually intricate and arduous computation of the consequent couple of obstructions vertices coordinates. The fire was ignited on book racks simultaneously which is an assumed condition in the warehouse and the doors were closed. The fire source was represented by a 0.9 x 0.45 m burning surface with 25727kW/m^2 max HRRPUA. Two types of materials, concrete (for walls), wood (for books) and inert material (for other surfaces) were used.

In Fig. 4, the fire simulation is illustrated. The red color point to turbulent gas clouds formed after the hit of fast spreading hot toxic gases onto the vertical back and curved side walls. Total computational time of 2 minute fire simulation on Core i3 990-X 3,46GHz, 4 GB RAM was about 7.04 hours.

For this case study flash over data is taken as 550 oC as Upper Layer temperature (ULT) criterion and HRR corresponding to ULT evaluated and is about 25727 KW. Thus according to the safety measures given and fire modelling software's data, the simulation output is classified in four. They are

- Max untenable HRR.
- Flame spread over adjacent floors.
- Flashover occur in the room.
- Oxygen concentration

It provides assessment for propagation of fire and its dynamics. Thus it is more relevant for study of spread behavior of plume and smoke. The data obtained from simulation are basically of qualitatively type. The output data so obtained are mostly correlatives and thus their practical and real scenario use is restrained.

Fig 6 shows the simulation time taken which was more than 6 hrs for simulating an output of 120secs in fire dynamic simulator for the given geometry of compartments and necessary tool.

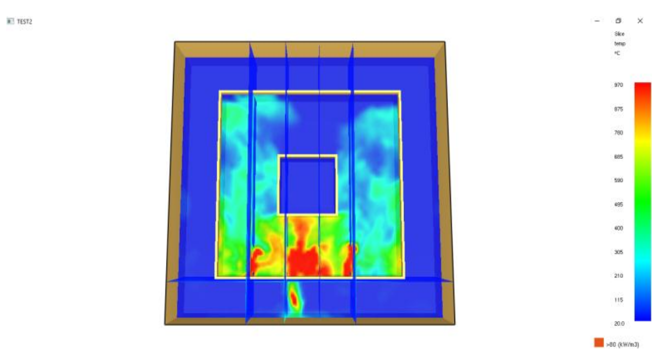

Fig 4. Fire spread model FDS Smokeview Topview output

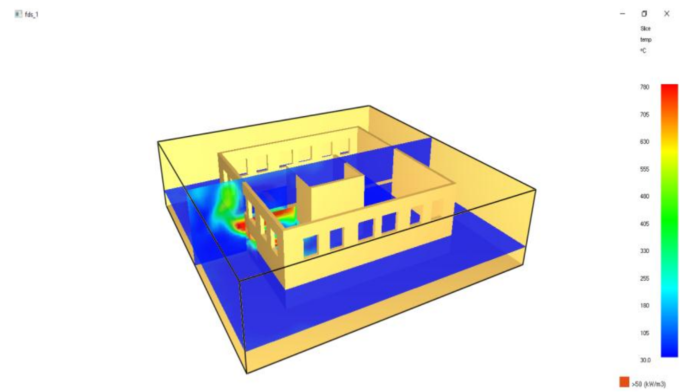

Fig 5. Fire spread model FDS Smokeview 3D output

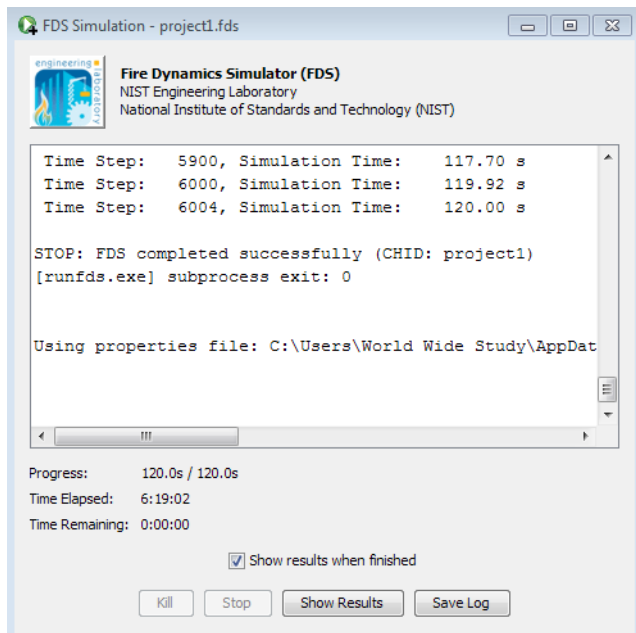

Fig 6. Progress display of FDS process

The simulation output from FDS in terms of four parameters as discussed in section 3 is shown in table 2 which shows the Heat Release Rate (HRR), percentage of oxygen concentration could not be determined by the model used in PyroSim

Table 2. FDS simulation output

Simulation output	Result
HRR	41482.24
Flame spread over adjacent floors	Yes
Flashover occur in the room.	Yes
Oxygen % concentration at 120 sec	~

Figure 7 shows the variation of heat release rate (HRR) with respect to time for the complete simulation period(120sec)

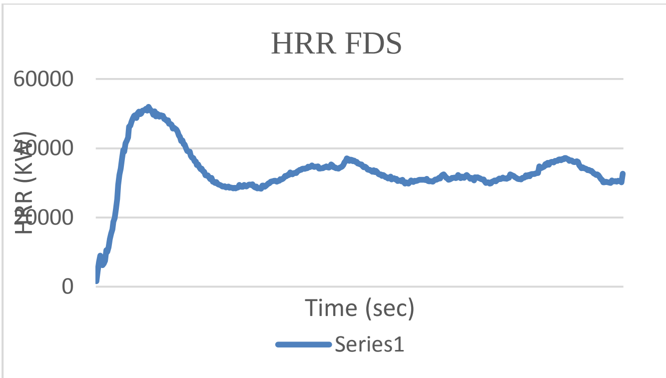

Fig 7. HRR simulation FDS

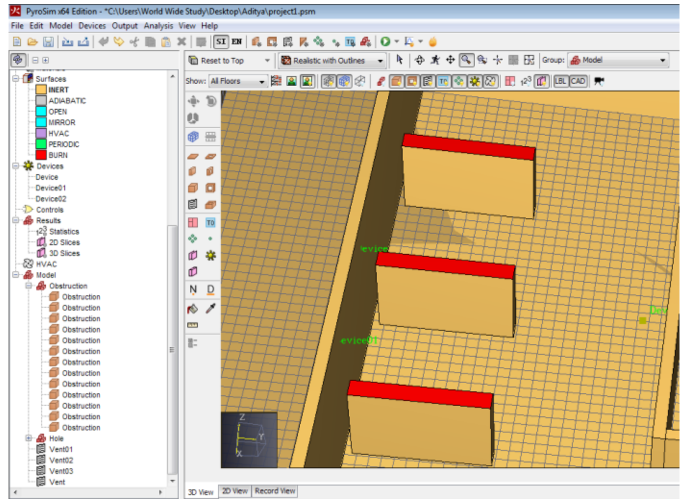

Fig 8: Representations of book racks in FDS

Fire load per square meter is calculated and per stack is about 1462.94 kg per rack. Flashover criterion is evaluated from standard by temperature rise of about 25727 KW with max HRR is about 51427 KW. Thus data are calculated by mathematical derivation, while HRR from the fire spread model and software are simulated and shown in result tables.

Oxygen concentration is a valuable data for predicting efficient evacuation model but in Fire dynamic simulator it was not possible to get the percentage of oxygen concentration using the limited inputs in the simulation.

Figure 9-10 shows the spreading of smoke particles in smokeview, this helps to determine the path and density of particles within the compartment which can be helpful for planning the evacuation plan or design of similar structure.

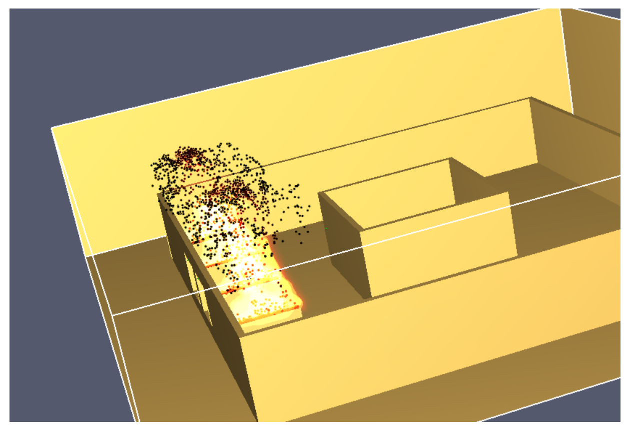

Fig 9. Simulation showing initial phase of smoke spread

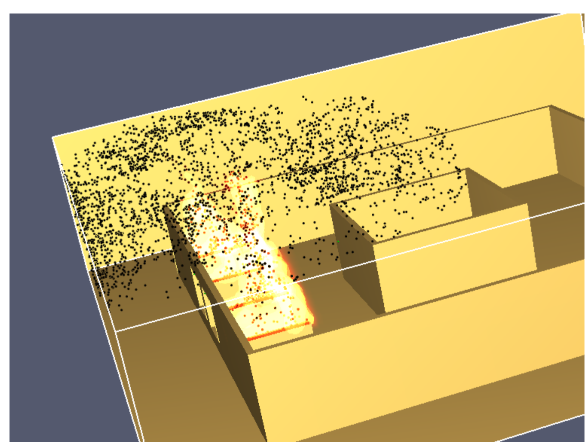

Fig 10. Simulation showing direction of smoke spread

4. CONCLUSION

Software simulation shows that there is extensive reach of the fire spread modeling tool, FDS. Its capability to evaluate and simulate both discreet and continuous random events is very unlikely. The independent fire model FDS is more suited and simple for fire dynamics simulation when it does not involve the human factor, making it difficult to understand real scenarios for human safety. PyroSim have an advantage of tools handling with numerous repetitious objects and positioning of objects against their correct position and allows avoiding the obligatory manually complex and arduous computation of numerous vertices coordinates which correspond to basic elements of the fire dynamic simulation geometry of solids

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