Fire Safety Assessment Studies in High Rise Assembly Buildings using Fire Dynamic Simulator

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Abstract

Indoors fires pose a significant threat in High rise assembly buildings especially with a lot of working personnel in various floors. In these type of buildings, fire protection, personnel and property safety play a key role. A study was carried out with Fire Dynamic Simulator (FDS) for a created model of High-rise assembly building with two different types of fire scenario to understand the spread of fire and smoke at various floors. Thus, by depicting a proper adoption of fire & smoke detection disposition considering these fire scenarios. The analysis was carried out by choosing the right type of positioning the detection method at various floors to minimize the response time.

Keywords: *Computer simulation, Multi-storey building fire, FDS, Smoke detection*

1. Introduction

Recently, computer simulation of fires has become a prominent tool for carrying out analysis and improvising of fire safety especially in production, process & assembly building dealing with explosion sensitive explosives. These usually require a high level of safety to prevent any type of fires near to process lines. The use of computer modelled Fire simulation itself presents a very understanding, economic and safe way of determination of potential fires for a given model. Fire Dynamic Simulator (FDS) is an Open Software developed by National Institute of Standards and Technology (NIST). FDS provides in aid to create the required model by defining any material properties. It solves the user created model with given set of inputs with assumption that the fire propagation is thermally driven (i.e. flow is of low-speed/low Mach) [1]. It also solves the other Thermo-chemical analysis equations like combustion of products, pyrolysis, heat transfers in conductive, convective & radiation between various phases like solid to gas, liquid to gas etc. [2]. The typical simple chemical reaction of fire in open environment used by FDS is as given below.

$$\text{Fuel} + 2\ \text{Air} \rightarrow \text{Products} \tag{1}$$

$$\text{Fuel} + 2\ (O_2 + 3.76\ N_2) \rightarrow x\ CO_2 + y\ H_2O + z\ N_2 \tag{2}$$

A graphical interface software that uses FDS was utilized to construct complex models for simulating different fire scenarios as per user requirements [3]. The software allows the user to visualise as well as construct the model in 3D. Computational Fluid Dynamics (CFD) in FDS solves the user model with given input boundary conditions by Navier-Strokes equation as per low speed approximations [2]. In our paper, two cases of indoor fires with different fuels were simulated in a High-rise assembly building. The fire model is rendered and observed for fire & smoke propagation over a period of time. The created model consists of various smoke detectors and thermocouples at each level to understand the smoke dynamics caused by each case of fire.

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ISBN - 978-93-95038-50-8 https://doi.org/10.37285/bsp.sasat2023.49

2. Creation of Model

Construction of Model was done through software having feature to import the 2D plan as a background image for creating model in 3D. The model generation is done in a rectangular Mesh of size 50 X 50 X 80 m with uniform cells of size 0.1 X 0.1 X 0.1 m for intended FDS simulation [4]. Thus, the entire domain space was divided into 500, 500 and 800 cells respectively in the direction of x, y and z axes.

The floor slabs and walls are of concrete material with 0.25 m thick. The building is in rectangular fashion with 30 (length) X 40 (width) m. The slabs are having partial openings to accommodate the vertical assembly operations at center. The typical construction creation of first floor slab and subsequent floors is shown in Figure 1. The design model of High-rise assembly building has 12 floors with floor to floor separation distance is 5 m. (Note: For understanding, the front entrance wall is in hide mode)

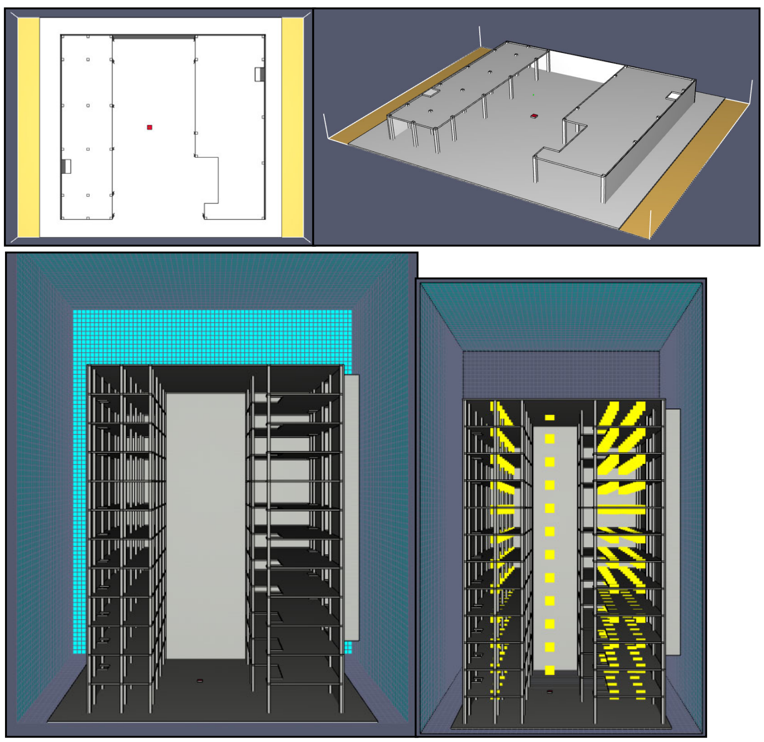


Figure 1: Stepwise construction of 3D model for High rise assembly building with Smoke Detectors & Thermocouples.

For ensuring the Open environment, computation boundary space of mesh is featured as Open vent at all directions except for ground. A stack of 1 X 1 X 0.25 m fuel is constructed in ground floor for generating fire. The top surface of the stack is maintained as burning surface (i.e. Burner) to enable the reaction initiation.

2.1. Inputs to Model

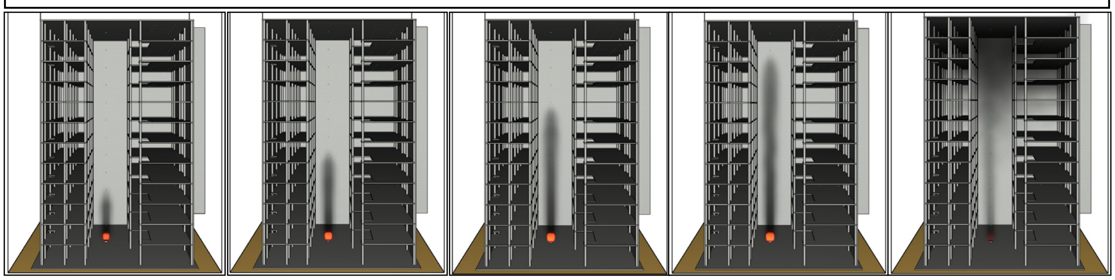
The modeling software requires the defining of the materials, surfaces, reaction and choosing of required results. In our model, we are generating a indoor fire with 2 different types of fuels i.e. cotton and wood at ground floor of the building so that fire developed in each case can be analyzed in an apt manner. The materials compositions along with reaction were given as input to the software [6]. The additional details like Heat of Combustion, pyrolysis, CO yield, Soot yield & Hydrogen Fraction were also provided for reaction [5] [7].

The characteristic Heat Release Rate (HRR) for the burning surface was obtained from experiments conducted. The typical profiles of HRR vs. Time graph were also co-related with profiles mentioned as per [5]. To get the temperature variation over the floors due to the fire in each case were depicted through positioning of 12 nos. of thermocouples above the burner surface. To understand the smoke propagation due to fires, 288 nos. smoke detectors of photoelectric type were positioned throughout the floors as shown in Figure 1. with obscuration threshold set at 7 %/m. The complete model is run in FDS simulation software for 200 seconds of fire simulation in Core i7-6700 @3.40 GHz, 8GB RAM.

3. Results and Discussions

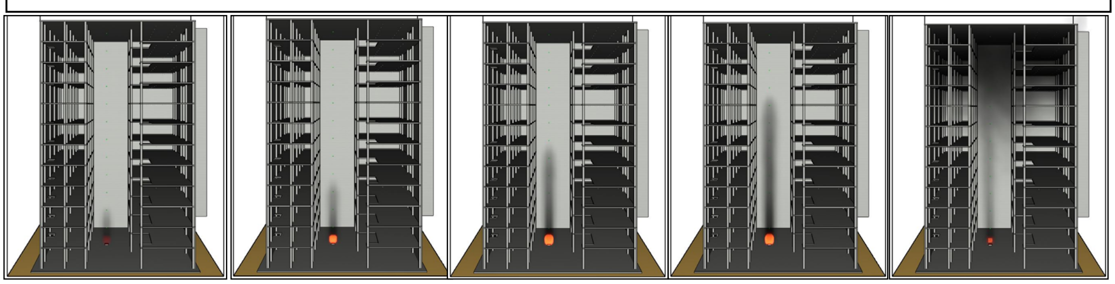
Based on the input parameters and boundary conditions given to the created model the CFD in FDS was run. The Figure 2. shows the illustration and visualization results of fire and smoke developments with time for wood & cotton fire scenarios.

Cotton Fire & Smoke Propagation with Time



At T = 10 s At T = 15 s At T = 20 s At T = 25 s At T = 200 s

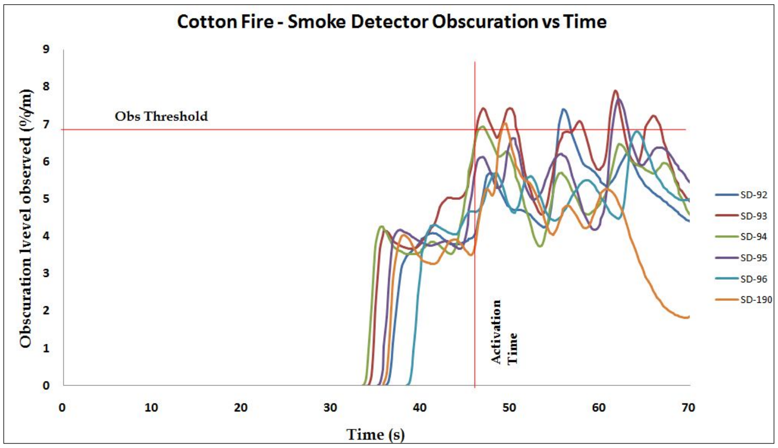
Wood Fire & Smoke Propagation with Time



At T = 10 s At T = 15 s At T = 20 s At T = 25 s At T = 200 s

Figure 2: Result images of Fire & Smoke propagation with Time.

It was observed a maximum flame length of 2.514 m was observed at ~16 s. for cotton stack fire whereas 3.293 m of maximum flame length was observed at ~20 s. It was also observed that rise in smoke height is faster in case of cotton fires. A plot of obscuration of the photoelectric sensors' levels observed that have been triggered alarm (i.e. reaching threshold obscuration 7%/m) in both fires for simulated time were shown in below Figure 3. The first detector activation time observed for wood fire is 47.30 s where as for cotton fire is 46.09 s.



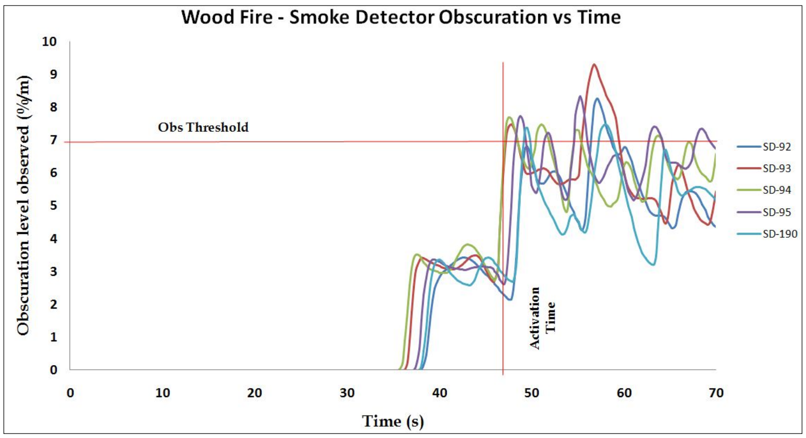


Figure 3: Plot of Obscuration of smoke detectors for wood & cotton fires with Time.

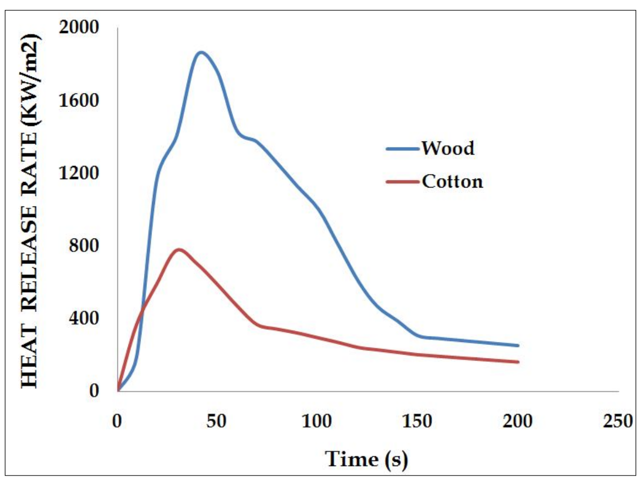
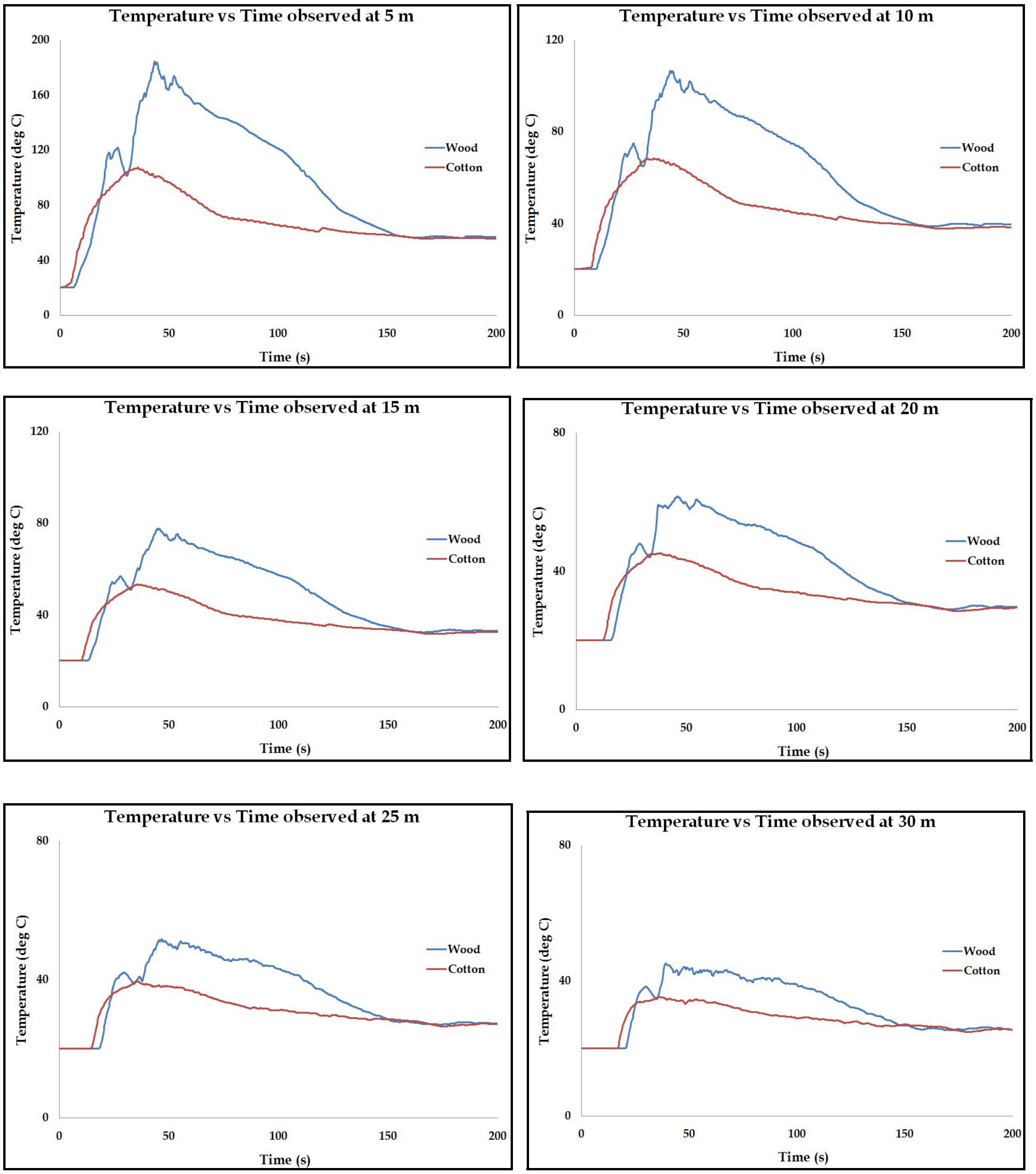


Figure 4: Plot of Heat release rate for wood & cotton fires with Time.

Plot of Heat release rate per unit area was shown in Figure 4 for both Cotton & Wood fire scenarios. Similarly, the temperature profiles observed in each floor was also depicted from the results is shown in Figure 5. A maximum of 184 ºC is observed for wood fire @ 44 s at 5-meter level where as a maximum of 107 ºC is observed @ 35 s for cotton. It is found that the temperature variation is decreasing for both fires on reaching top floors of assembly buildings.



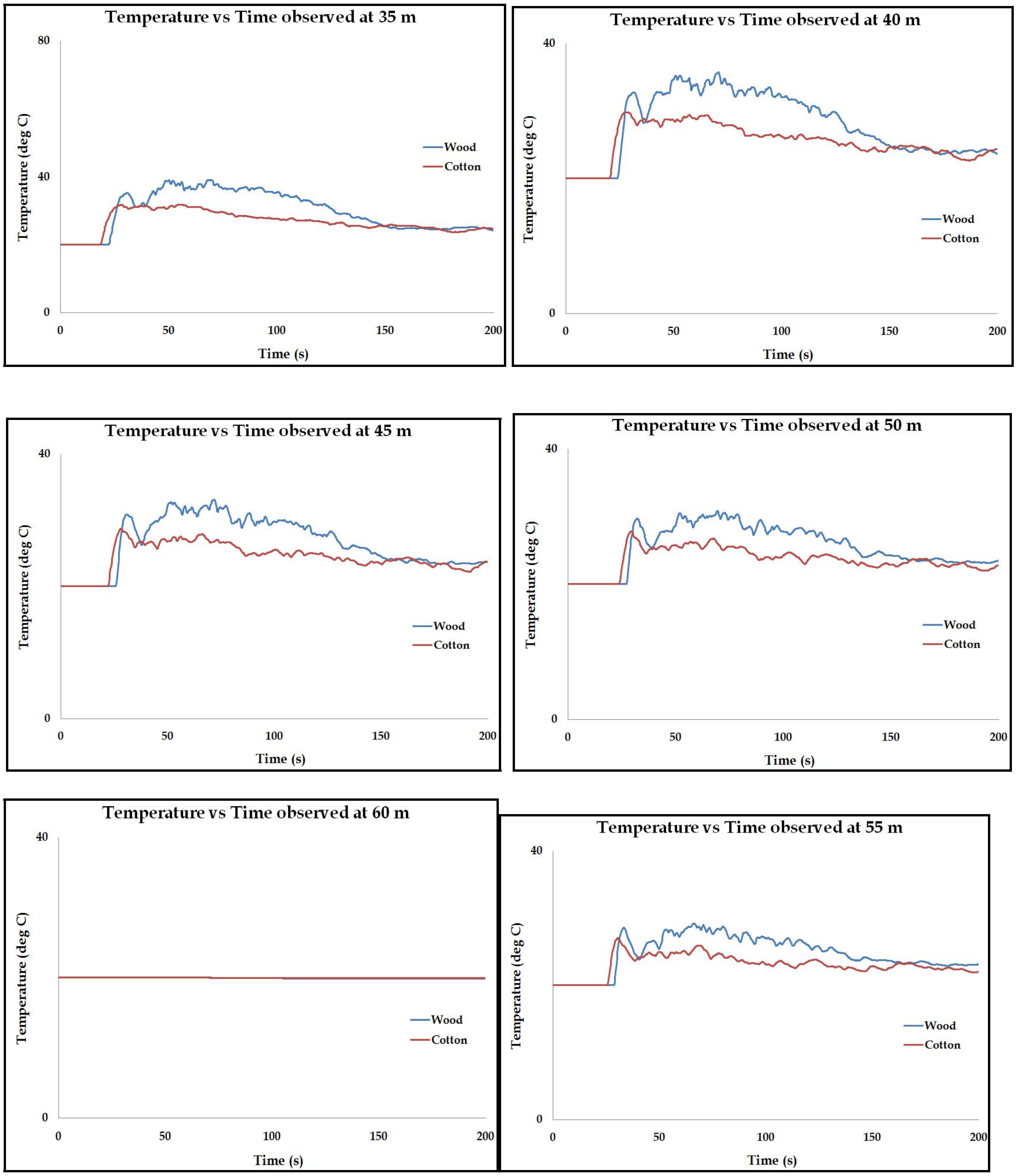


Figure 5: Plot of Temperature profiles for wood & cotton fires with Time.

4. Conclusion

A High-rise assembly building consisting of 12 floors was constructed in FDS to understand the two different fuel fires i.e. cotton and wood with identical stack dimensions. The entire building is equipped with 288 nos. of photoelectric smoke sensors and 12 nos. thermocouples at each floor to analyze the temperature and obscuration levels for entire simulation period of 200 s. It was observed that for both fire scenarios the smoke level reaches the ceiling height at around 47s. But the temperature values observed for wood fires is more than that of cotton fires. It is also inferred from results that the obscuration levels at top floors are filling significantly than at lower levels. Thus, from the data depicted we can see the Heat sensors with photoelectric type provided in lower floors provide a significant less response time where as the photoelectric type at top floor provides the efficient way to detect fires at top as well as bottom floors.

Additionally, for simulation of fires in further fine mesh for these types of complex structure geometry requires multi-core computer for processing the FDS simulations. Other flammable materials in addition to cotton & wood stack fires can also be added to the existing simulation for studying the impact of multi case fire scenarios. Also, aspects of safe evacuation from the fires at top levels of Multi-storey building can also be studied in future.

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