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Simulation of Fire in Super High-Rise Hospitals Using Fire Dynamics Simulator (FDS)

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ABSTRACT

Background: Among various types of disasters, fire constitutes a significant threat to life and property in urban and rural areas. Protection the hospitals against fire is very important due to presence of disable persons, lack of awareness and expensive devices and equipments in the hospitals. The present study was aimed to fire simulation in the super high-rise hospital.

Methods: This cross-sectional descriptive study was conducted in a super high-rise hospital (17 floor) in 2018-2019. The project was divided into two steps: 1) Preparation of 3D model of the hospital using 3D CAD Modeling Software; 2) The computational fluid dynamics (CFD) technique is used to predict the fire dynamics (smoke propagation, temperature distribution, heat release rate and total energy) in the hospital using the Fire Dynamic Simulator (FDS).

Results: The fire simulation results showed that after 10 seconds from the onset of fire in the third floor of the hospital with the intensity of 1620/79 kW, the temperature, total energy and heat release rate reaches 87 °C, 5640 kW and 937 kW, respectively. According to the simulation results, after 600 seconds, the temperature, total energy and heat release rate were 610 °C, 928 kW and 933 kW, respectively, which the fire had reached to an uncontrollable stage.

Conclusion: By correction of staircases and elevator shaft, the spread of fire can be controlled effectively. To improve the level of fire risk and appropriate actions during emergency situation in super high-rise hospital, required measures especially in the area of containment and extinguishment including buildings design for smoke control, fire alarm and extinguisher systems.

Keywords: super high-rise hospital, fire simulation, fire dynamics simulator

INTRODUCTION

With the rapid growth of modern city processes and the progress of architectural science and technology, numerous super high-rise hospitals continue to be constructed (1). Compared to normal compartment fires, super high-rise hospital fires have unique characteristics: (a) presence of disable persons and lack of awareness (b) fire spreads quickly and human evacuation, (c) complex building structures and boundary environments cause particular fire evolution behaviors, (d) smoke control and fire-fighting difficult, (e) emergency rescue is challenging and the amount of time required to extinguish the fire is long, allowing the fire and smoke to readily spread (2).

Once super high-rise hospital fire breaks out, it would rapidly expand and lead to evacuation difficulties and casualties, mainly because stairways, elevator shaft, ducts and pipes just like a stacks and become ways of the rapid spread of the fire and smoke (3). In addition, the stack effect is more pronounced in vertical shaft structures with an increase in height, by which the thermal smoke moves more rapidly from the lower to upper floors (4). Smoke and toxic gases, such as carbon monoxide, hydrogen cyanide, and hydrogen chloride, are the most fatal factors in fires. The smoke particles decrease the visibility range in the space resulting in that the people cannot find the way out (5).

Identifying methods for simulation of fire in super high-rise hospitals, ensuring safe evacuation of internal staff and patients, and reducing casualties and property damage have attracted extensive attention in past decades (1). Thus, this study selected an actual super high-rise hospital to set up specific fire scenarios, establish a fire dynamics simulator (FDS) model, and analyze the direction and type of smoke spread and fire growth. The results from this study can potentially help in furtherance of research in a particular field of knowledge and can be a guidance in administering the hospital health and safety promotion program.

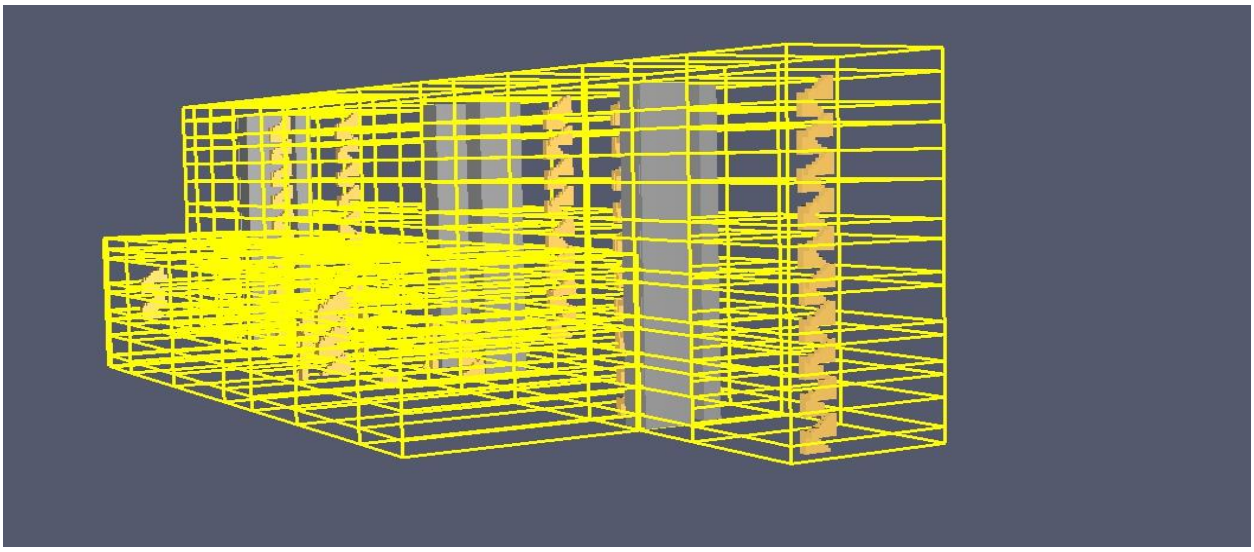

Figure 1. Drawing 3D model of hospital building by 3D CAD Modeling Software

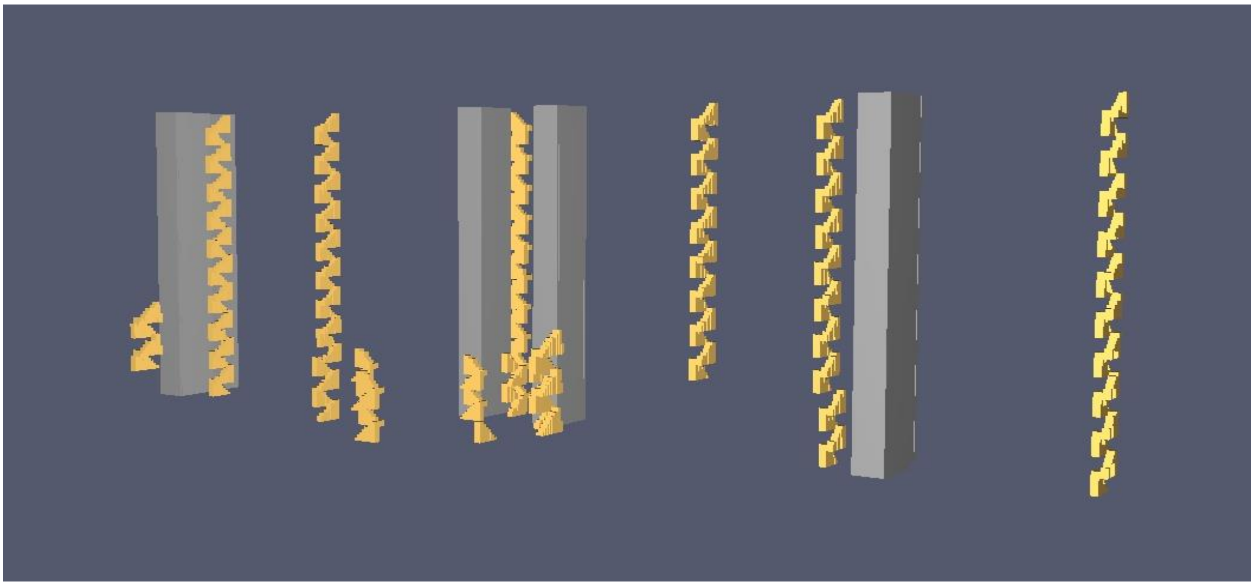

Figure 2. Drawing 3D model of elevator and stairwell by 3D CAD Modeling Software

METHODS

This cross-sectional descriptive study was conducted in a super high-rise hospital (17 floor) in 2018-2019. The project was divided into three steps:

Building Overview and Preparation of 3D model

The research object of this study was the super high-rise hospitals, located in Tehran, Iran. The building has an approximate height of 52 m, with a total floor area of 60,000 m^2, a building area of 50,000 m^2 for 14 stories above ground level, and a building area of 9,720 m^2 for 3 stories located underground. The building consists of a steel-reinforced concrete frame reinforcing a concrete core-tube structure. **Figure 1** shows a model of the whole building based on the 3D computer aided design (CAD). However, to save computational cost and enhance the simulation accuracy, a simplified model was applied in this paper, presented in **Figure 2**, simulating the elevator and stairwell of a 17-story high rise hospital with a height of 52 m.

Fire Dynamics Simulator (FDS)

The present study is based on the computational fluid dynamics (CFD) technique using Fire dynamic simulator (FDS,v.5). This code was developed and published by the National Institute of Standards and Technologies (NIST), U.S. Department of Commerce (6). The FDS is a large-eddy simulation (LES) code used to model low-mach flows driven by combustion heat release and buoyancy. The core algorithm of FDS is an explicit predictor-corrector scheme, second-order accurate in space and time. It solves numerically a form of the Navier-Stokes equations appropriate for low-speed (Ma < 0.3), thermally-driven flow with an emphasis on smoke and heat transport from fires. The formulation of the equations and the numerical algorithm are contained in the FDS Technical Reference Guide (7). Verification and Validation of the model are discussed in the FDS Verification (8) and Validation (9) Guides. Smokeview (SMV) is a visualization program used to display the output of FDS and consolidated fire and smoke transport (CFAST) simulations.

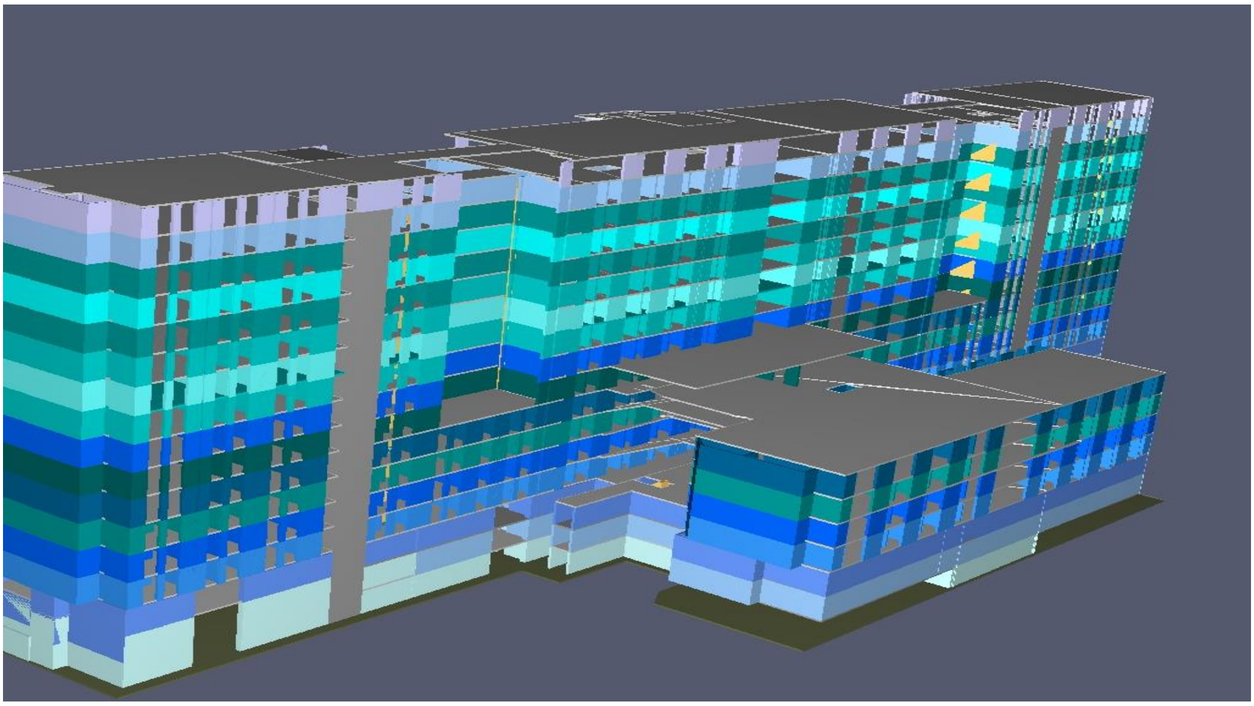

Figure 3. The super high-rise hospital structure model used in FDS

Table 1. Hospital fire information

Time (Second)	Temperature (°C)	Q_TOTAL (kW)	HRR (kW)
0.61	30	1620	51.64
2	30	4000	393
100	245	4290	940
200	296	3190	937
300	370	2350	939
400	430	1730	936
600	610	928	933

Fire Simulation

Hospital fires, with same areas as that in the tests, were set as fire sources. Prior to the simulation, a model should be built. Then, a train of grids should be set and divided into basic units according to the grid independence; therefore, a reliable grid-set can be obtained. Thereafter, general fire parameters, such as the heat release rate (HRR), smoke concentration, visibility, velocity, and temperature can be monitored and outputted after the computation, which is mainly based on viscous fluid equations, i.e., the Navier–Stokes equations (10). The heat outputs of these hospital fires were set according to the heat release rate per unit area (HRRPUA) in FDS.

RESULTS

According to the setting of the fire scenario, typical scenario were selected for use in the analysis of the simulation results. The building structure model in the FDS is displayed in **Figure 3**.

The fire simulation results showed that after 10 seconds from the onset of fire in the third floor of the hospital with the intensity of 1620/79 kW, the temperature, total energy and heat release rate reaches 87 °C, 5640 kW and 937 kW, respectively. According to the simulation results, after 600 seconds, the temperature, total energy and heat release rate were 610 °C, 928 kW and 933 kW, respectively, which the fire had reached to an uncontrollable stage. The descriptive information on fire parameters of the studied super high-rise hospital was presented in **Table 1**.

The rate of smoke spreading was exceptionally high, with an adjacent open area being affected almost every 50 s. At 60 s, the smoke had filled the entire room and spread to the top of the outside aisle, whereas visibility in the room exceeded the visual distance of a person. At 216 s, the smoke spread to the view of the west side of the building and gathered at the top of the staircase, further threatening safety evacuation of personnel. At 600 s, the smoke filled the entire space of super high-rise hospital, and all areas were invisible, which seriously affected the normal actions of the personnel. **Figures 4**, **5** and **6** shows the smoke spread in the hospital building in 60 s, 216 s and 600 s, respectively. The fire spread fast in vertical direction.

DISCUSSION

In this study, fire simulation in super high-rise hospital was investigated. As the fire occurred in a room in the hospital, smoke, temperature, heat release rate and total energy promptly augmented the space, and the smoke spread along various gaps to other areas. During this process, the fire and smoke spreading in vertical direction has two main ways: one is the elevator shaft and the other is the staircase. Taking measures to control the two ways in fire course, the spread of fire can be controlled effectively.

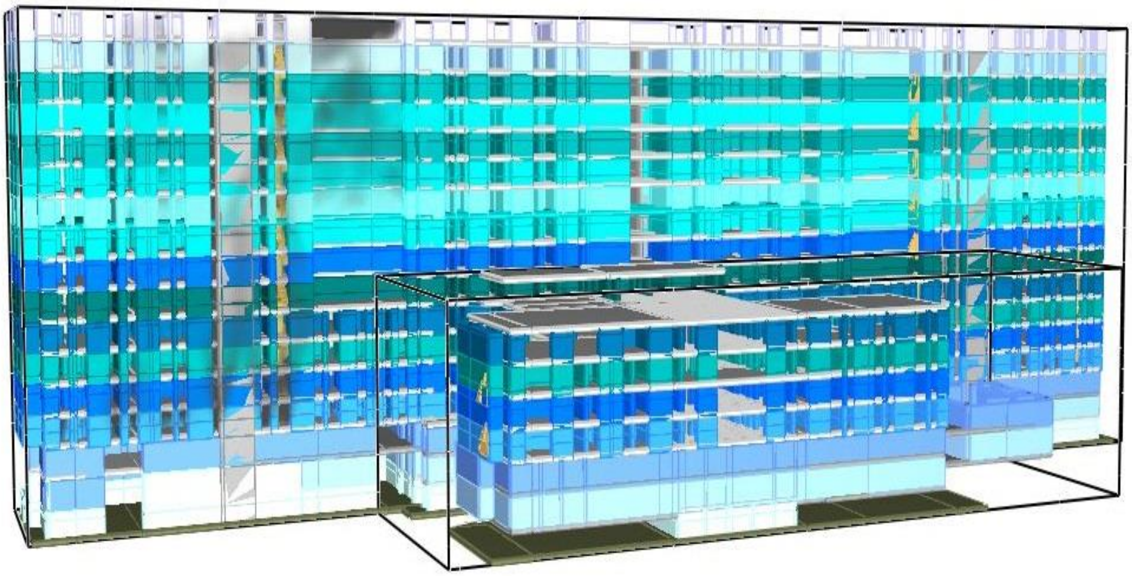

Figure 4. Fire simulation in the super high-rise hospital structure in 60 s

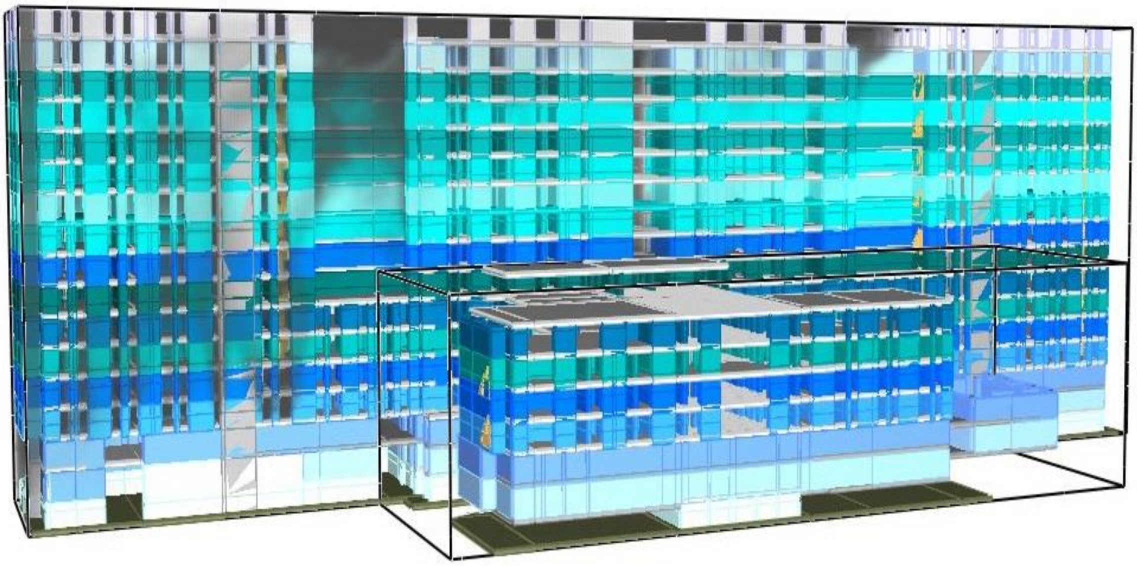

Figure 5. Fire simulation in the super high-rise hospital structure in 216 s

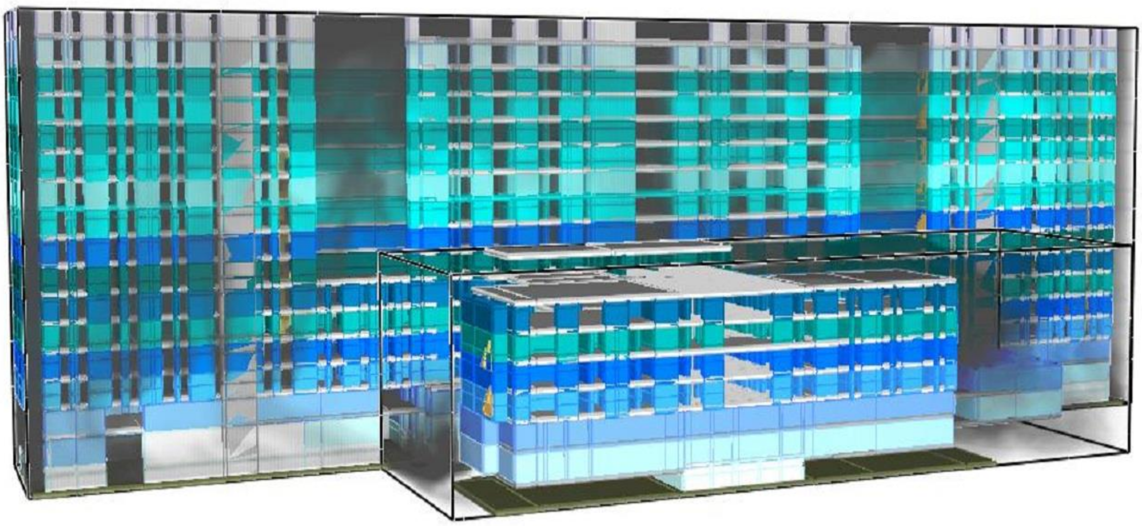

Figure 6. Fire simulation in the super high-rise hospital structure in 600 s

According to the temperature detected by FDS software, as presented in **Table 1**, the temperature inside the room was higher than 60°C, which exceeded the temperature range bearable to the human body. In the room, the temperature was higher at greater distances from the fire source; after 600 s, the temperature detection point tended to remain stable. Relevant studies have showed that the air temperature changes can reach up to 1000 °C in the height of 145m of high-rise-building fires at 558s (11). Temperature decreases obviously along with increasing the distance from the fire surface. The average temperature is sharply reduced by about 20°C, 20m away from the fire surface (11).

The speed at which smoke spread and lowered was extremely fast, and smoke always began to accumulate and spread from the corner and the ceiling. **Figure 5** shows fire situation at 600s in simulation. The surface burns vigorously and the fire produced a considerable amount of smoke up to the roof. Relevant studies have demonstrated that smoke is the primary cause of death during fires (12,13). Therefore, the first step during evacuation is to leave the fire room quickly and avoid remaining in a corner, which can effectively prevent harm caused by smoke. stairwells of super high-rise hospital must be equipped with fireproof doors, fire doors need to stay close, if the door does not close, not only encourage the chimney effect, smoke will spread easily to the fire escape stairs, obstruct the personnel evacuation of fire escape staircases.

CONCLUSION

By correction of staircases and elevator shaft, the spread of fire can be controlled effectively. To improve the level of fire risk and appropriate actions during emergency situation in super high-rise hospital, required measures especially in the area of containment and extinguishment including buildings design for smoke control, fire alarm and extinguisher systems.

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