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# Numerical solution of smoke spread from fire in a residential tower by FDS simulation software

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**Abstract.** Fire simulation software programs such as Pyrossim Software can be the most applicable instruments in field of determining the smoke behavior at the time of fire. Using fire simulation, one can analyze different scenarios at the time of fire in places such as railway and subway tunnels, road tunnels, factories, residential and commercial complexes and other places. In this study, one of the high-rise residential towers has been simulated. Baran Tower has been located in a land with approximate area of $2200\,\mathrm{m}^2$ and in margin of Golshan Street. The tower with height more than 110 m has infrastructure about $30\,000\,\mathrm{m}^2$ in 22 stories. In this study, the smoke focus points and also the effects of a controller have been analyzed, which can cause sudden change in heat transfer diagram at the moment. Baran-2 tower has been located in a land with an area about $2200\,\mathrm{m}^2$ and in margin of Golshan Street. The results obtained from this study can be specification of places with higher oxygen concentration and change in type of solid fuel to gas, which can change counters of temperature, vision, oxygen, carbon dioxide and carbon monoxide.

**Key words.** Fire, smoke simulation, FDS, PYROSIME, fire dynamic simulation, residential tower.

## 1. Introduction

Nowadays, with increased urbanization and increased number of high-rise buildings, the issue of safety in these buildings at the time of fire has been changed into one of the most important issues. In the construction sector as one of the most important sectors of Iran, which has attracted 30 % of employed people directly, and with regard to 22 types of industry affiliated to this sector, it can cover more than 50 % of employed people of the country. Moreover, final product made by this sector is the houses used by ordinary people and can be effective as fixed financial capital

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for many years. Hence, necessity of economic saving is very important.

In construction industry, different methods and technologies are available to achieve maximum capacity and productivity in field of utilization of facilities and high-rise construction is one of the most important and effective methods. In majority of counties, whether developed or developing, it is tens of years that the method is being used to maximize utilization of facilities and equipment in construction industry and it is today the dominant method for construction in big cities of the world. Economic saving achieved by tower construction is as follows:

Infrastructural facilities of urbanization such as road construction, piping for water, wastewater, gas, cabling, electricity and telephone and the equipment needed by each of them can be the most costly and at the same time the lowest profitable investments for the governments. Hence, governments significantly prevent length and width extension of big cities and encourage vertical growth of cities, so that the equipment can be used in maximum level with lowest possible expense for urban infrastructural investments and the investments can be used in highly profitable economic departments with taking the said savings. Tower construction can lead to maximum use of infrastructural services of urbanization by the citizens with increased density of person per hectare in big cities. Hence, it can lead to considerable economic saving in national economy on one hand and can also reduce cost of living in big cities on the other hand.

## 2. Methods and materials

### *2.1. Heat transfer rate*

To define heat transfer rate, the concept of mixing fraction has been firstly analyzed. Mixing fraction means the ratio of mass of a subset of types to total mass in volume. Mixing fraction is a function of place and time, which is usually presented as $Z(x,t)$. Now, for more explanation, 1-step reaction of fuel and oxygen is analyzed [7].

$$\mathrm{C}_x\mathrm{H}_y\mathrm{O}_z\mathrm{N}_a\mathrm{M}_b+\vartheta_{\mathrm{O}_2}\mathrm{O}_2 \to \vartheta_{\mathrm{CO}_2}\mathrm{CO}_2+\vartheta_{\mathrm{H}_2\mathrm{O}}\mathrm{H}_2\mathrm{O}+\vartheta_{\mathrm{CO}}\mathrm{CO}+\vartheta_{\mathrm{s}}\mathrm{S}+\vartheta_{\mathrm{N}_2}\mathrm{N}_2+\vartheta_{\mathrm{M}}\mathrm{M}\,, \quad (1)$$

where $M$ refers to number of moles of molecular weight and stoichiometric factor, $\vartheta_{\mathrm{s}}$ refers to the fuel produced to soot ratio, which is correlated to soot yield $y_{\mathrm{s}}$ using the equation

$$\vartheta_{\mathrm{s}} = \frac{W_{\mathrm{F}}}{W_{\mathrm{S}}} y_{\mathrm{s}} W_{\mathrm{s}} = X_{\mathrm{H}} W_{\mathrm{H}} + (1 - X_{\mathrm{H}})\, W_{\mathrm{C}}\,. \quad (2)$$

For soot, it is assumed that a mixture of carbon and hydrogen is shown with hydrogen atomic fraction as $X_{\mathrm{h}}$. The following equation is used to obtain CO.

$$\vartheta_{\mathrm{CO}} = \frac{W_{\mathrm{F}}}{W_{\mathrm{CO}}} y_{\mathrm{CO}}\,. \quad (3)$$

The equation of mixing fraction is defined as:

$$Z = \frac{1}{Y_{\mathrm{F}}^{\mathrm{I}}} \left( Y^{\mathrm{F}} + \frac{W_{\mathrm{F}}}{xW_{\mathrm{CO_2}}} Y_{\mathrm{CO_2}} + \frac{W_{\mathrm{F}}}{xW_{\mathrm{CO}}} Y_{\mathrm{CO}} + \frac{W_{\mathrm{F}}}{xW_{\mathrm{S}}} Y_{\mathrm{S}} \right), \tag{4}$$

where $Y_{\mathrm{F}}^{\mathrm{I}}$ is the fuel mass fraction [7].

Now, the heat production rate equation is defined as:

$$\dot{q}''' = \frac{\rho \min \frac{Y^{\mathrm{F}} Y_{\mathrm{O_2}}}{s}}{\tau}, \tag{5}$$

where coefficient $C$ is considered at 0.1.

FDS considered heat production rate to $2500\,\mathrm{kW/m^3}$ as default.

### 2.2. Heat release rate (HRR)

One of the most underlying parameters used in fire dynamic simulation software is Heat Release Rate (HRR) [7].

$$\dot{q}_{\mathrm{f}}'' = \frac{f(t)\dot{q}_{\mathrm{user}}''}{\Delta H}. \tag{6}$$

The desired HRR per surface unit is determined by the user, and the rising time $f(t)$ is based on which mas loss rate is estimated.

### 2.3. Results

In [5] the authors simulated a room with mechanical ventilation system using FDS software. The experimental and simulated results are presented in Fig. 1. It could be observed that experimental sample has lower error percentage compared to simulated sample. In Fig. 1, T1 value refers to experimental results, T2 refers to simulated results in [5] and T3 refers to simulated results in this study.

Three residential apartments exist in floor 7 of Baran Tower. The starting point of fire is assumed to be in one of the apartments. In Table 1, details of the network have been specified (meshing and solution network).

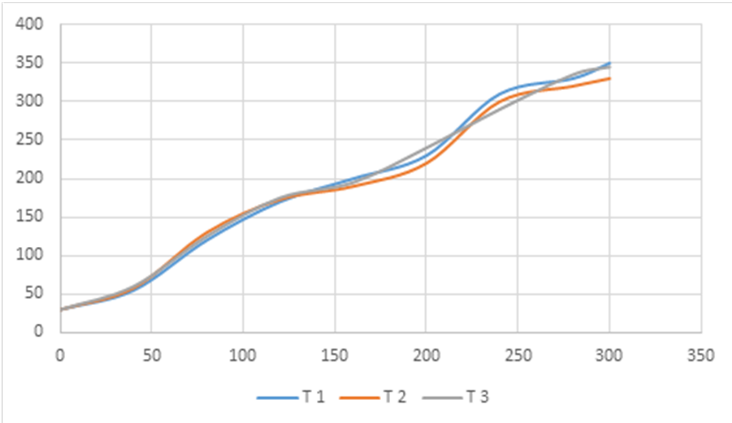


Fig. 1. Diagram (temperature-time) of comparing simulated values in [5] and simulated values in this study; experimental values in temperature graph are per time

Table 1. Network information

| Network type | Mesh size | Network zone | Solution time | Simulation time |
|---|---|---|---|---|
| Heterogeneous | 0.4 | 1 | 200 hrs | 100 s |

## 2.4. *Burner place*

The burner place in this scenario is presented in Fig. 2.

Fig. 2. Burner place in floor 7

The results obtained from simulation are presented here. For better vision, objects and some walls are hidden; although this can affect the results. In the following, smoke spread, counters of temperature, oxygen density are presented in Fig. 3. In Fig. 3, it is observed that after opening all doors in second 200 after fire beginning, smoke is spread rapidly in whole floor.

Fig. 3. Smoke spread status after 20 s and 240 s

### *2.5. CO concentration counters*

In Fig. 4, CO concentration counters are illustrated for different times. It could be observed that even after opening doors, CO emission spread is not high.

## 3. Conclusion

In this study, fire has been simulated in Baran Residential Tower and the way of smoke spread caused by fire. Also, the temperature, oxygen concentration, CO and $CO_2$ concentration have been analyzed with regard to 3 different points for fire. With analysis of obtained counters from the simulation, those points can be detected that have less smoke accumulation and paths with better visibility, which can be significantly helpful at the time of fire in this tower. Another result obtained from this study is the time that methane is considered as fuel instead of wood. In this case, spread of $CO_2$ in the space is faster than previous state. To minimize the calculations, the simulated mode has been simplified as much as possible, since the issue of spread and emission is significant in this space. With regard to oxygen and $CO_2$ concentration counters, it could be found that concentration of these gases is decreased in space after a while; although CO concentration was increased to the end of simulation process.

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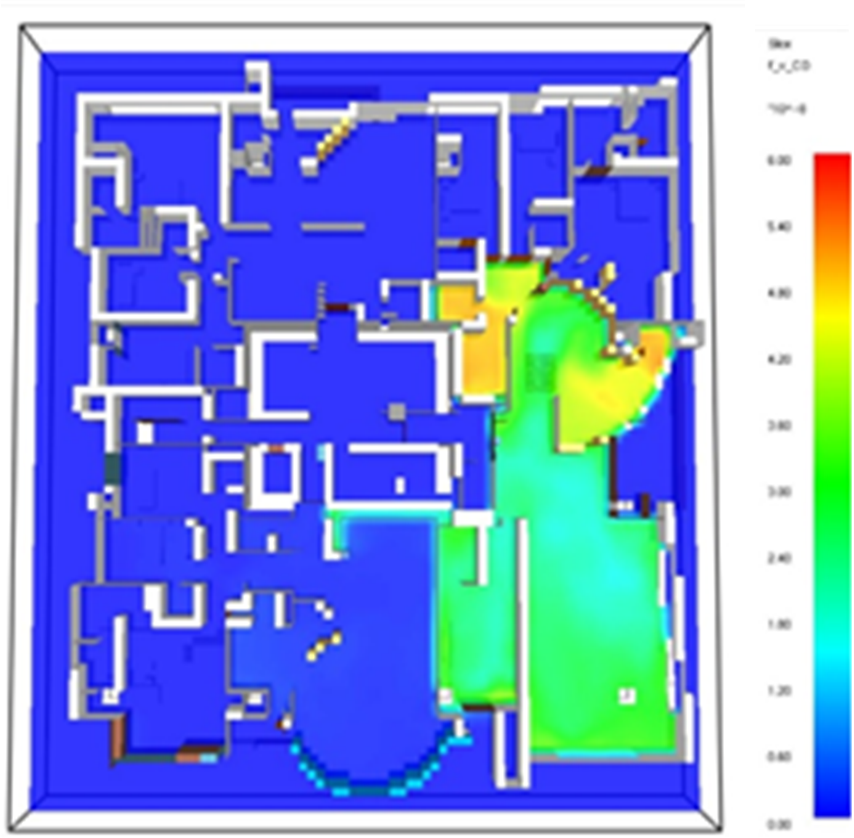


Fig. 4. CO concentration counters 50 s after beginning of fire

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