FDS Analysis of a High-Rise Residential Building in İstanbul

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Abstract

The main threat to human life in high rise building fires is failures in safe evacuation of occupants. Evacuating people from high rise structures is especially challenging due to higher number of people and longer exit paths. In this study, a high rise residential building in İstanbul over 40 floors having height of over 170 m is analysed using an advanced Fire Dynamics Simulator software. With fire analysis performed, important properties like fire spread, smoke spread, combustion toxicity in critical regions throughout structure are investigated. Time dependent fire effluent in these regions are presented as well as maximum survival times of evacuees standing in these regions. Simulation outcomes of analysis also gave information about occurrence of tenability conditions in enclosures of high rise building which has high impact on evacuation times and strategies. Main outcome of this research is that zones placed in critical egress parts could reach to very threatening level in a relatively short time. It is also observed that smoke is the first effect to surpass the tenability limit, whereas convected heat and carbon monoxide quantity are likely to be the most threatening hazards.

Keywords: HRR, FDS, Fire, Evacuation, Tenability

1 Introduction

Tenability can be defined as a set of criteria to ensure safe evacuation of occupants of a building in case of fire. Therefore, occurence times of untenable conditions are very important for performance based fire safety evaluation of buildings, especialy for the high-rise buildings since they require much more time to evacuate building safely compared to middle or low-rise buildings. When time-oriented perfomance based fire safety evaluation is considered, there are two crucial concepts: ASET and RSET. The former, RSET is a term defined as required time for residents to evacuate building when fire occured. The time needed before conditions become untenable is explained with the term called ASET, the available safe egress time, means the time between beginning of fire and compartments become untenable. Consequently, one of the main purpose of this study is to show untenability occurence time on the critical egress paths. Another objective of this study is to acquire fire effluent concentrations in the volumes called zones on the critical egress paths during simulation, as occupants have to pass from these zones to reach building exit. These fire effluents can be counted as smoke, heat, carbon monoxide (CO), carbon dioxide (CO_2), Hydrogen Cyanide (HCN) and Oxygen (O2) depletion. Toxicity data acquired can be used in Fractional Effective Dose (FED) calculations, which is defined as ratio demonstrating the capacity of a human to resist accumulated toxicity through breathing in his/her blood, indicate how close someone is to the incapacitation state. Purser (89) first derived the equations to calculate FED ratios of occupants trying to evacuate in case of fire, so incapacitation, which is defined as a state of being disabled and unable to act or function, times can be obtained. Presenting survival time of an evacuee when met with these fire effluents is also targeted in order to show how threating toxicity levels can be achieved based on the scenario applied in the high rise structure.

2 Methodology

FDS analysis is performed in SMARTFIRE software. SMARTFIRE performs FDS analysis based on fundamental principles of fluid dynamics. It could create valid, accurate outcomes based on greater sophistication and minimal use of empiricism in field models. Fire effluent data such as temperature, radiation, smoke density, toxic gases can be acquired in zones in structures during the simulation period. Since FDS data is compatible with evacuation analysis software EXODUS, the fire effects on the evacuation behavior on the occupants can be obtained. This can have an important impact on determining mitigation strategies.

The floor plan of the high-rise building selected for the case study is provided in Figure 1. CAD floor model is transferred to SMARTFIRE Case Specification Environment so that fire properties of a room fire could be created. In order to form a room fire, a survey is conducted to decide furniture size and placements and floor covers based on the room plans gathered from various architectural drawings. As a room fire, the living room is selected to give the worst case fire scenario. Furniture layout as well as ignition order and time is provided in Figure 2.

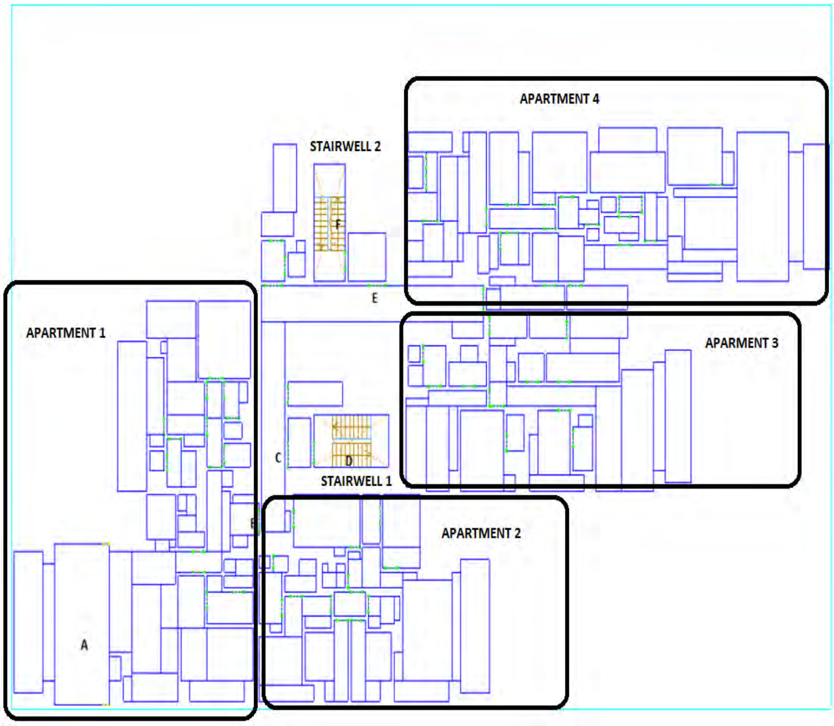

Figure 1. Floor plan and location of critical zones.

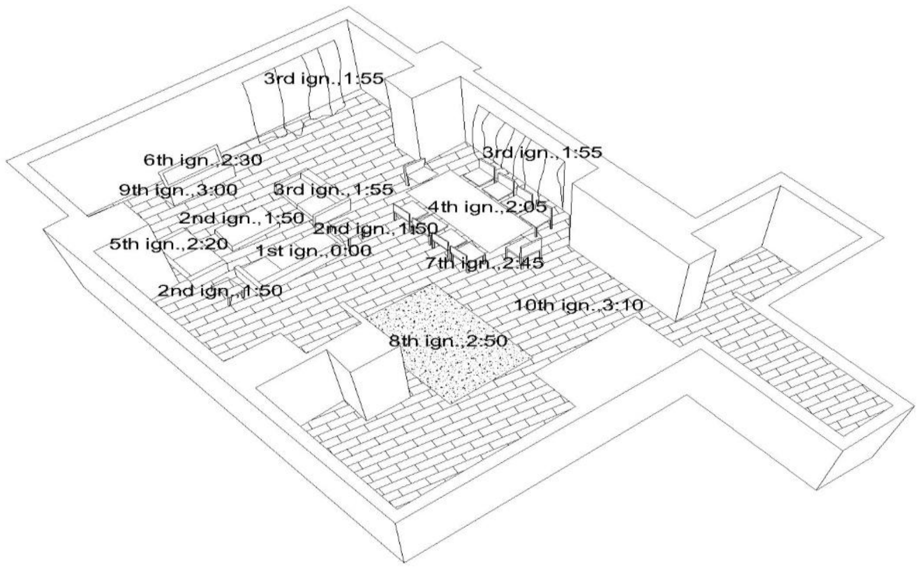

Figure 2. Furniture layout, ignition order and times in the living room.

In order to create heat release rate curves, published cone calorimeter and furniture calorimeter experiment data is investigated. Regarding data such as heat release curve, mass and material content of each furniture placed in rooms, average soot yield of all combustible materials are collected. Heat of combustion values of material in furnitures are also obtained as well HCN percentage of all combustible materials in this step. In order to describe combustion in modelling, a suitable and most representing material, that is polyurethane foam, is chosen in the combustion model. To define toxicity in model, (Gottuk, 1992) toxicity model is used so that it could be possible to gather information for CO yield, CO_2 yield, HCN yield production and O_2 consumption.

In formation of living room heat release curve, a scenario is generated by assuming 3 seat sofa is first item to ignite. Then, all combustible material content in living room are assigned trigger conditions so that they can be ignited through flame temperature, heat flux or auto ignition temperature. When one of these triggering condition is met, the item is assumed to be burned completely. Accordingly, ignition times surrounding first burning objects changed between 110 seconds and 190 seconds, whereas first object observed to ignite is side table near 3 seat sofa while last object is parquet. In following step, a pool curve is formed for living room and heat release rate of objects are summed, when their corresponding ignition times are reached.

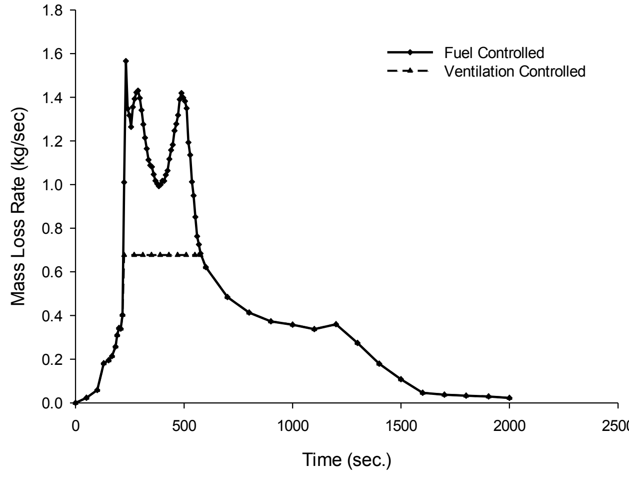

Figure 3. Mass Loss Rate curve of living room fire for both ventilation and fuel controlled cases.

After creation of the living room fire curve, effect of ventilation opening included which caused a decrease in curve since opening area of 4 m^2 caused ventilation controlled fire. Once combustion model is activated to increase accuracy in toxic yields production during simulation, it is also required to apply mass loss curve instead heat release curve. To do that, heat release curve is divided by effective heat of combustion value of living room. Consequently, ventilation controlled mass loss rate is applied in model as seen in Figure 3.

3 Results

Fire scenario is selected such that it could be possible to observe one of the most threating type room fire, that is th living room fire. Table 1 summarizes, properties of scenario to be examined. Fire origin defines the term that fire does not spread to other rooms or floors. Room type is living room also implies that only items placed in living room are ignited. Sprinkler activation refer that any active protection like sprinkler system has no decaying effect on the fire curve whereas open doors allow the fire effluents.

Figure 3 demonstrates plan of the fire floor for a 46-storey high-rise building in İstanbul. While A, B, C, E are the zones on the fire floor, D and F are the zones in the stairs. A is in the fire room, B is in the apartment 1 exit, C is in the corridor next to stairwell 1 entrance door and E is in the corridor next to stairwell 2 entrance door. D is the zone in the stairwell 1 on the fire floor, whereas F is the zone in stairwell 2 on the fire floor.

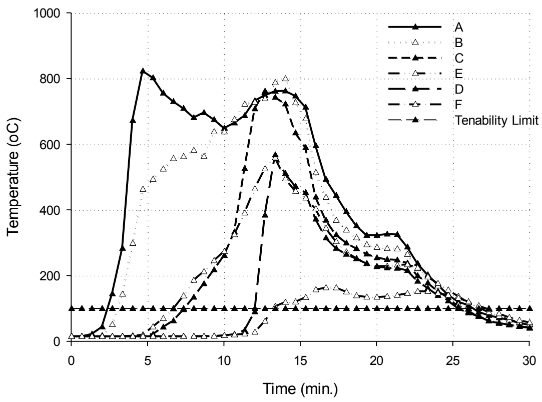

Figure 4. Temperature distributions in the critical zones on the fire floor during the simulation.

The tenability limit for temperature is defined as 100 ^oC (Airah, 2011). As seen in figure 4, this limit value is exceeded in each zone. Maximum temperature values at location A, B, C, D, E and F are 823 ^oC, 811 ^oC, 763 ^oC, 576 ^oC, 579 ^oC, 164 ^oC, respectively.

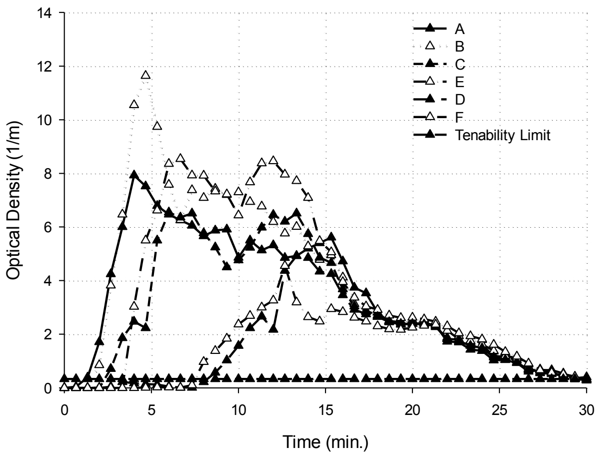

Figure 5. Smoke distributions in the critical zones on the fire floor during the simulation.

Although optical density is defined as the ratio of the intensity of light falling upon a material and the intensity transmitted in Physics, this term is simply used to indicate the amount of smoke in the compartment in fire engineering. The tenability limit for optical density is 0.33 m^{-1}. As seen in figure 5, this limit value is exceeded in each zone. Maximum optical densities at location A, B, C, D, E and F are 8.15 m^{-1}, 11.79 m^{-1}, 6.7 m^{-1}, 5.25 m^{-1}, 8.84 m^{-1}, 4.56 m^{-1}, respectively.

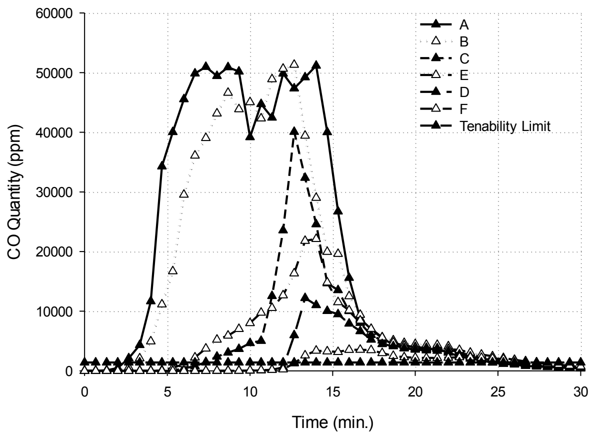

Figure 6. CO quantity in the critical zones on the fire floor during the simulation.

The tenability limit for carbon monoxide (CO) density is set at 1400 ppm. As seen in figure 6, this limit value is exceeded in each zone. Maximum CO quantities at location A, B, C, D, E and F are 51644 ppm, 53945 ppm, 42192 ppm, 12690 ppm, 24200 ppm, 3573 ppm, respectively.

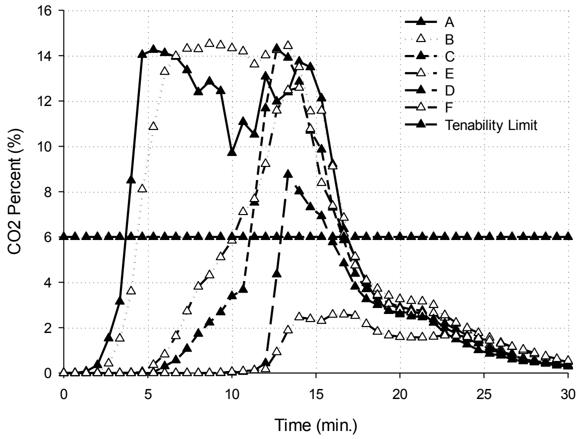

Figure 7. CO_2 percentages in the critical zones on the fire floor during the simulation.

The tenability limit for CO_2 percentage is determined as 6 percent, As seen in figure 7, this limit value is exceeded in each zone except zone F. When the maximum percentages of carbon dioxide in critical regions are examined, the highest CO_2 percent observed in the fire room (A) is 14.4 (%). Highest CO_2 percent values at location B, C, D, E and F are 14.6 (%), 14.6 (%), 9.0 (%), 12.9 (%), 2.6 (%), respectively.

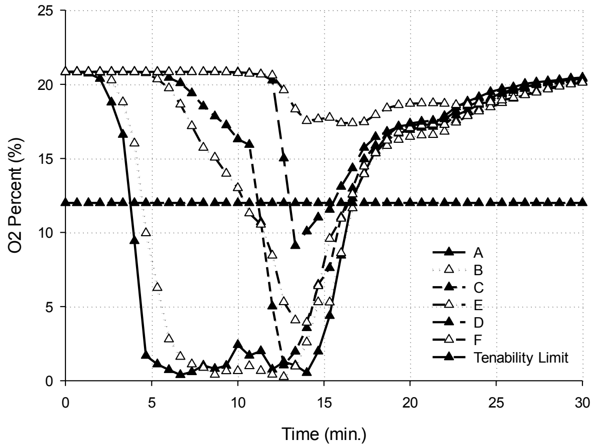

Figure 8. O_2 percentages in the critical zones on the fire floor during the simulation.

The tenability limit for O_2 percentage is defined at 12 percent. As seen in figure 8, this limit value is exceeded in each zone except zone F. When the minimum percentages of the oxygen in critical regions are examined, the lowest O_2 percent observed in the fire room (A) is 0.39 (%). Lowest O_2 percent values at location B, C, D, E and F are 0.26 (%), 0.69 (%), 8.76 (%), 3.49 (%), 17.35 (%), respectively.

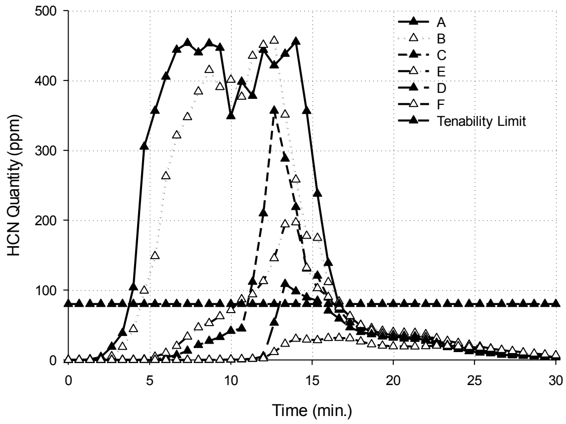

Figure 9. HCN quantity in the critical zones on the fire floor during the simulation.

The tenability limit for HCN quantity is set at 80 ppm. As seen in figure 9, this limit value is exceeded in each zone except zone F. When the maximum hydrogen cyanide quantities in critical regions are examined, the highest HCN quantity observed in the fire room (A) is 459 ppm. Maximum HCN quantities at location B, C, D, E and F are 480 ppm, 375 ppm,112 ppm, 215 ppm, 31 ppm, respectively.

Table 1. Overall tenability occurrence times in the zones.

Zone	Tenability Occurence Times in the Critical Zones (min:sec)					
	Heat	Smoke	CO	CO_2	Low O_2	HCN
A	2:24	1:15	2:30	3:50	3:55	2:55
B	3:00	1:45	3:05	4:25	4:30	4:30
C	7:24	2:35	7:20	11:15	11:15	11:10
D	12:05	8:10	12:15	12:55	12:55	12:55
E	6:45	3:40	6:10	10:05	10:20	10:20
F	13:15	7:35	12:45	-	-	-

Table 1 summarizes the tenability limit of all the overall hazardous effects in critical zones A-F. Smoke is dominant tenability condition and occurs earlier than all other effects. Heat and CO concentrations can also reach threating levels in a short time. CO_2, HCN and O_2 depletion are also able to create danger in the stairwell 1 with a delay compared to other effects, while these effects can not create danger in the stairwell 2.

Table 2. Survival times against highest concentrated hazardous effects in the critical zones.

Zone	Survival Times Against Hazardous Effects (min:sec)				
	Heat	CO	CO_2	O_2 Depletion	HCN
A	0:00	0:28	0:16	0:03	0:00
B	0:00	0:27	0:13	0:02	0:00
C	0:00	0:35	0:14	0:04	0:00
D	0:00	2:01	4:25	4:49	16:30
E	0:00	1:02	0:35	0:17	0:00
F	2:02	7:32	123:07	499:11	35:00

Exposing to high concentration of toxic substances or extreme heat may lead to incapacitation, and eventually death for residents who are in the high rise structure in case of fire. Survival times are given based on highest amount of toxic gas quantity and convected heat in Table 2. Data provided in Table 2 are instantaneous and answer the question of how much can someone stay alive in the critical zones at highest rate of hazardous effect at corresponding zone. At Zone A and Zone B, all hazardous effects can reach such a threatening level that people standing at these zones become incapacitated in a quite short time. At Zone C and Zone E, in the corridor parts that are next to stair entrances, even though CO, CO_2 and O_2 depletion can reach such a high level to cause incapacitation in a very short time, yet most danger comes from HCN quantity and convected heat. At zone D and F, that are the zones in the stairs, main threat comes from convected heat and CO quantity, as CO_2 quantity, O_2 depletion and HCN quantity become less effective on evacuees trying to evacuate. Toxic effects observed at zone D are more intense compared to zone F, since zone D is located in the stair that is closer to the fire origin.

4 Conclusion

Smoke is the first effect evacuees encounter that decrease angle of sight to reduce movement speed significantly, so that lead these people expose more to hazardous effects. Those who do not leave the apartment for any reason such as sleeping, not taking clues seriously or taking bath during this period are likely to experience difficulties. Those living on a higher floor than the fire floor and who do not reach to the stairs on the fire floor before tenability limit is surpassed, may suffer from hazard effects quite heavily according to ASET/RSET analysis.

Zones placed in the stairs are affected from the threatening hazards with a remarkable delay compared to the corridor on the fire floor. Although fire based threats require less time to reach to the corridor, a bit longer time needed to pass from corridor to the stairs, which makes evacuation process slightly easier.

In the high rise structure, CO quantity and convected heat are likely to be most threatening hazards for evacuees due to the fire, as stairs that are main egress components are contaminated with these hazards more compared to other types of hazards. The presence of other harmful gases in the environment and the fact that the carbon dioxide increases the inhalation of CO provides a combined effect, making it more possible for evacuees to reach incapacitation state.

When the effect of the distance between the location of stairs and fire origin on the formation of toxic conditions is examined, it is observed that the stair located further away from the fire origin is less affected by the harmful effects of the fire. Although CO and heat concentrations reach threating levels in the distant stairs, it is still much lower in the stair that is closer to fire origin. CO_2, HCN and O_2 depletion creates almost no danger in the distant stair, as there are quite high survival times even at highest concentrations and tenability limits are not attained, while these toxic effects can still create danger in the near stair.

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