A Study for the Effect of Fire Initiated Location on Evacuation Success Rate

Jin A Ryu, Ga Ye Kim, Hee Sun Kim

Abstract**—**As the number of fire accidents is gradually raising, many studies have been reported on evacuation. Previous studies have mostly focused on evaluating the safety of evacuation and the risk of fire in particular buildings. However, studies on effects of various parameters on evacuation have not been nearly done. Therefore, this paper aims at observing evacuation time under the effect of fire initiated location.

In this study, evacuation simulations are performed on a 5-floor building located in Seoul, South Korea using the commercial program, Fire Dynamics Simulator with Evacuation (FDS+EVAC). Only the fourth and fifth floors are modeled with an assumption that fire starts in a room located on the fourth floor. The parameter for evacuation simulations is location of fire initiation to observe the evacuation time and safety. Results show that the location of fire initiation is closer to exit, the more time is taken to evacuate. The case having the nearest location of fire initiation to exit has the lowest ratio of successful occupants to the total occupants. In addition, for safety evaluation, the evacuation time calculated from computer simulation model is compared with the tolerable evacuation time according to code in Japan. As a result, all cases are completed within the tolerable evacuation time.

This study allows predicting evacuation time under various conditions of fire and can be used to evaluate evacuation appropriateness and fire safety of building.

Keywords**—**Evacuation safety, Evacuation simulation, FDS+Evac, Time.

I. INTRODUCTION

As buildings become higher and more occupied, the number of fire accidents is gradually raising and fire leads to considerable loss of life. Therefore, the evacuation is concerned and many studies have focused on simulating evacuation with high accuracy. Huang et al. [1] perform simulation study of evacuation in high rise buildings, taking various combinations of stairs and elevators. For evacuation planning in Japan and Taiwan, Shih et al. [2] conduct a virtual reality based feasibility study of evacuation time compared to traditional calculation method. Proulx [3] reports experimental results to observe evacuation time and movement in apartment building. Tan et al. [4] suggest an agent-based evacuation model in which the evacuee's knowledge is considered to observe the influence of spatial change on the evacuation performance. Lee [5] performs simulation of fire and evacuation to evaluate fire and evacuation safety in high-rise residential-commercial buildings. Kim [6] performs evacuation simulation on the aged care hospital, and proposes effective evacuation planning. Park [7] conducts simulation with a case of using a kitchen fire extinguishing system and compares with a case without using that, to investigate the effect of a kitchen fire extinguishing system on evacuation safety.

In South Korea, even though evacuation safety has been evaluated by simulation and experiment in many studies, relatively few studies on effects of various conditions on evacuation time and safety have been reported. Previous studies have mostly focused on evaluating the safety of evacuation and the risk of fire in certain types of buildings. The evacuation is affected by a combination of psychological factor and environmental factor, that is, evacuation behavior and evacuation safety vary with conditions of building in fire, such as location of fire initiation, gender and age of occupants and whether doors are opened or not. Therefore, there is a need to establish data about factors that affect evacuation by simulating fire and evacuation.

This paper aims at investigating evacuation time and safety through the commercial program, Fire Dynamics Simulator with Evacuation (FDS+Evac). Towards that goal, evacuation is simulated and effect of parameter on evacuation time and the ratio of successful occupants to the total occupants are investigated. Then, the evacuation time obtained by simulation is compared with the tolerable evacuation time calculated by Japanese regulation.

II. EVACUATION SIMULATION APPROACH

This study uses Fire Dynamics Simulator with Evacuation (FDS+Evac) developed by the Fire Research Division in the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST).

Evacuation simulations are carried out on a 5-floor building with 2 exits located in Seoul, South Korea. The height of one story is 2.4m and floor plan is shown in Fig. 1. Walls and slabs are considered as concrete with 200mm of thickness and properties of gypsum board are included for ceilings. Inflammable materials are placed at the height of desk in all rooms except hallway because inflammable material should not be put in hallway by law. The room in which fire is initiated is 6 m×7m and has the 16 m^2 size of inflammable material. In addition, northwestern winds blow at the speed of 2.17m/s. Fire is initiated in the left corner of a room located on the fourth floor. Since heats tend to move toward upper floor, the fourth and fifth floors of five stories are modeled. Based on the actual occupants of the building, the men and women are located in the right room and left room respectively and people inside the

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building are created with virtual agents. In order to evaluate the evacuation behavior on a horizontal floor, the agents are only placed on the fourth floor. Properties of the agents, such as body sizes, walking velocities, pre-evacuation time and force constants, use the default values provided by FDS+EVAC and the initial positions of agents are generated randomly within the assigned room. In addition, the detection times and reaction times of the agents are assumed to follow uniform distribution ranging from 5 to 15. The default values about the body dimensions and the unimpeded walking speeds of agents according to FDS+EVAC are listed in Table I.

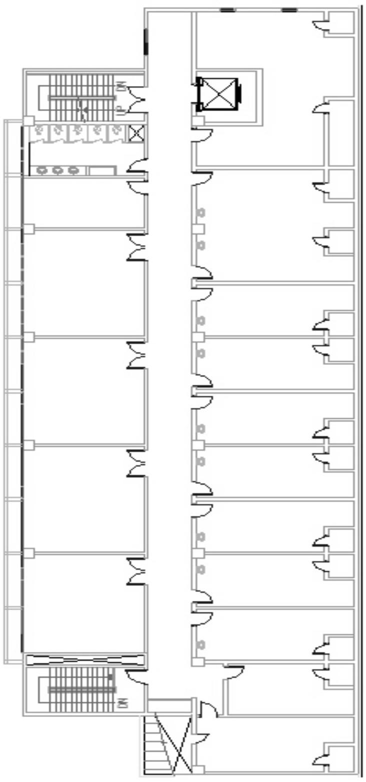


Fig. 1 Floor plan

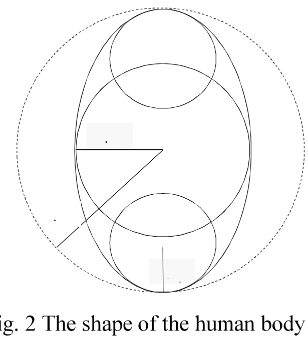


Fig. 2 The shape of the human body [8]

TABLE I
WALKING SPEEDS AND BODY DIMENSIONS IN FDS+EVAC [8]

Body Type	R_d(m)	R_t/R_d	R_s/R_d	d_s/R_d	Speed(m/s)
Male	0.270±0.020	0.5926	0.3704	0.6296	1.35±0.02
Female	0.240±0.020	0.5833	0.3750	0.6250	1.15±0.02

Parameter for evacuation simulations is chosen as the location of fire initiation to investigate evacuation time and evacuation safety. The locations of fire initiation have three cases as shown in Fig. 3.

The fire and evacuation simulations are done at the same time in order to observe effects of the smoke and the fire on the movement of the evacuating humans. As the agents have random initial positions, the results may not be exactly same. Thus, in this study, simulations are repeated ten times with the same model and the averaged evacuation time is presented. In addition, the fire load is designed as heat release rate curve as shown in Fig. 4 and uses fire growth phase for office building, based on the literature reviews [9]. Also a maximum heat release rate is prescribed as 876.19kW/㎡, according to the literature reviews [10].

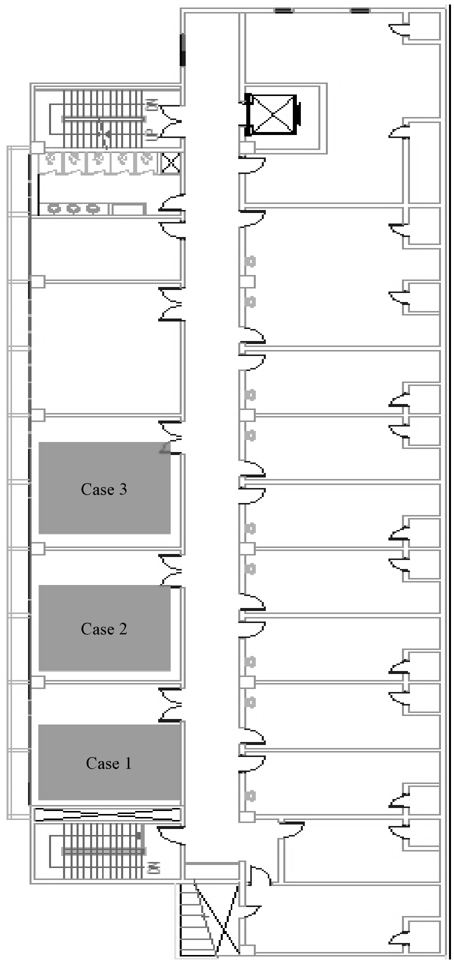


Fig. 3 Three cases depending on the location of fire initiation (■: Location of fire initiation)

III. RESULTS OF EVACUATION SIMULATION

A. Location of Fire Initiation

There are three cases depending on the location of fire initiation. As shown in Fig. 5 (a), Case 1 has a fire scenario that fire is initiated from the nearest room to the exit. In Case 2, fire starts in the next room of Case 1. In addition, Case 3 has a fire scenario that fire starts in the furthest room from the exit. Case 2 and Case 3 are shown in Figs. 5 (b) and 5 (c), respectively.

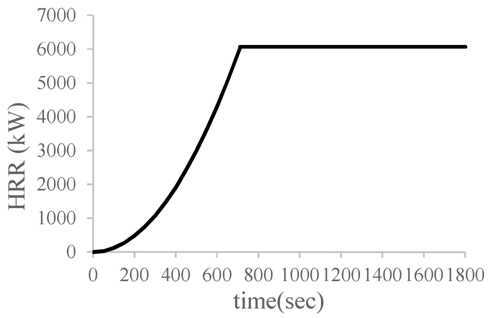
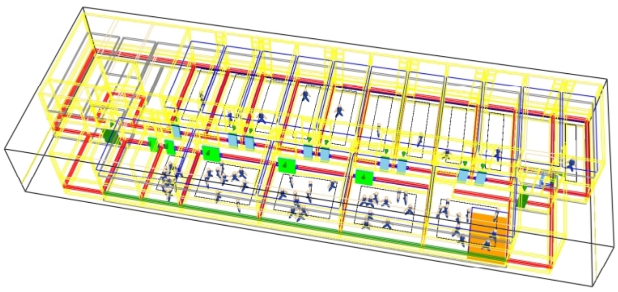
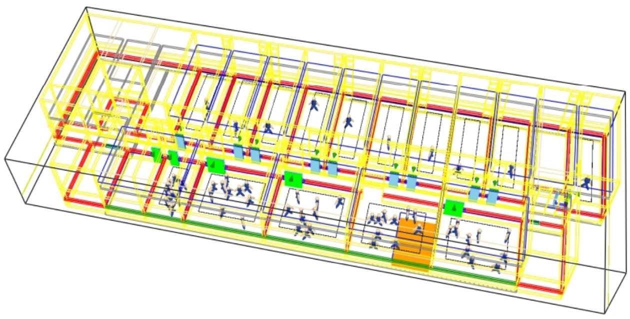


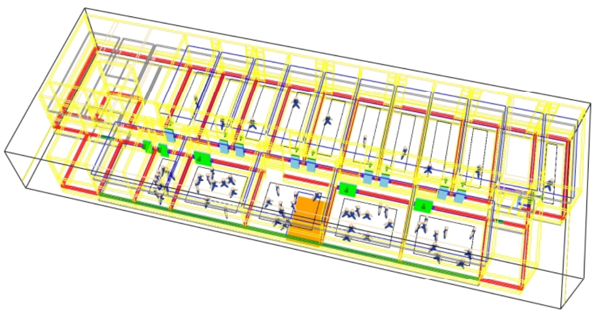
Fig. 4 Heat release rate curve



(a) Case 1



(b) Case 2



(c) Case 3

Fig. 5 Distribution and location of agents

The simulation results of three cases are shown in Table II.

When the fire is initiated from the room that is close to the exit, 80% complete the evacuation in 82sec and the rest of the agents fail to evacuate. In Case 2 and 3, 95% complete the evacuation in 69sec and 96.3% finish the evacuation in 64.4sec, respectively. The results show that location of fire initiation is closer to the exit, the more time is taken to evacuate. Also the case having the nearest location of fire initiation to the exit has the lowest ratio of successful agents to the total agents.

TABLE Ⅱ
EVACUATION TIME AND THE NUMBER OF AGENTS COMPLETED EVACUATION

	Case 1		Case 2		Case 3	
	Time (sec)	Evacuee	Time (sec)	Evacuee	Time (sec)	Evacuee
1	82	48	70	57	65	58
2	82	48	65	57	65	58
3	82	48	65	57	65	58
4	82	48	70	57	65	58
5	82	48	70	57	65	58
6	82	48	70	57	65	58
7	82	48	70	57	65	58
8	82	48	70	57	62	57
9	82	48	70	57	65	58
10	82	48	70	57	62	57
Average	82	48	69	57	64.4	57.8
Evacuation success rate (completed agents /the total agents)	80%		95%		96.3%	

B. Evacuation Safety

Additionally, this study evaluates evacuation safety for three cases described in the previous section. To evaluate the evacuation safety of occupants, the actual evacuation time is compared with the tolerable evacuation time. When the actual evacuation time is less than the tolerable evacuation time, the occupants are considered to be safe. The tolerable evacuation time is decided by the regulation defined by Japan, "New Guideline for Building Hazard-prevention [11]" The regulation prescribes for evacuation on floor and calculates the tolerable evacuation time by using the area of floor. The actual evacuation time is the time taken for occupants to move from their positions to areas of safety in building fires and is presented by result of evacuation simulation. In addition, it means the sum of detection, reaction and movement time.

The tolerable evacuation time is calculated by:

$$T_t = 8\sqrt{A} \quad (1)$$

where, A : the area of floor.

The floor area of the building is 767㎡ and the tolerable evacuation time is 221sec. Analytical results of evacuation safety are shown in Table III. The times required to evacuate the building range from 64.4 to 82 sec, that is, the actual evacuation time of each case is less than the tolerable evacuation time. In other words, in all cases, the evacuation is safely completed within the tolerable evacuation time.

TABLE III
SAFETY ASSESSMENT ON EVACUATION

	The actual evacuation time (sec)	The tolerable evacuation time (sec)	Evacuation safety
Case1	82		OK
Case 2	69	221	OK
Case 3	64.4		OK

IV. CONCLUSION

To investigate effects of parameter on evacuation, evacuation simulation is carried out. Parameter for evacuation simulation is chosen as the location of fire initiation. After that, the ratios of successful occupants to the total occupants and evacuation time are presented and compared.

Also, in order to evaluate evacuation safety of each case, the tolerable evacuation time is compared to the actual evacuation time calculated by simulation. The conclusions are as follows:

1. Location of fire initiation has also a lot of influence on the evacuation. When the location of fire initiation is closer to exit, it takes a long time to evacuate and the ratio of successful occupants to the total occupants is comparatively low.
2. From the evacuation safety check, the agents in all cases complete the evacuation within the tolerable evacuation time.

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