International Journal of Advanced Culture Technology Vol.9 No.4 363-375 (2021)
DOI https://doi.org/10.17703/IJACT.2021.9.4.363

IJACT 21-12-43

Evacuation Safety Evaluation of Tourist Hotels with the Fire Alarm Method

[1]Sung-Chun, Moon, [2]Ha-Sung, Kong*

[1]Graduate student, Dept. of Fire and Disaster Prevention, Woosuk Univ., Korea
[2]Associate professor, Dept. of Fire and Disaster Prevention, Woosuk Univ., Korea.
119wsu@naver.com

Abstract

The purpose of this study is to analyze the safety of evacuation using the Pathfinder program for the alert at once, the priority alarm method, the priority alarm method for the four floors above, and the sequential priority alarm method, which is a modification of the priority alarm method specified in the tourist hotel building. Currently, in Korea's National Fire Safety Codes (NFSC), fire alarm methods are compulsorily applied differently depending on the number of floors and total floor area of a building. Although the growth rate is getting faster due to the diversification of building structures, it is still an obstacle to improving evacuation safety to comply with the standardized fire alarm method in NFSC. As a result of the experiment, the evacuation time was found to be faster with the priority alarm method for the four floors above than the priority alarm method applied to the specific firefighting object. Compared to the priority alarm method applied to the tourist hotel, which is a specific firefighting target with 5 or more floors and a total floor area of more than 3,000m2, the time was shortened by 3.7 seconds when measured by applying the priority alarm method for the four floors directly above. This indicates that it is necessary to take measures to select a fire alarm method suitable for the structure and environmental conditions of the building rather than applying the uniform NFSC regulations.

Keywords: *Fire Alarm Method, Tourist Hotels, Evacuation Safety Evaluation, Sequential Priority Alarm*

1. INTRODUCTION

Travel culture is stagnant as social distancing continues due to COVID-19. However, as the number of travelers staying in Korea increases with the hopes of developing a vaccine and treatment for COVID-19, and reviewing a system 'live with Corona' to manage COVID-19, the need for risk management of accommodation facilities is becoming more urgent.

The fire hazard of accommodation facilities is largely due to the fact that the fire load is high due to the bedding, *etc*. in the rooms, which increases the risk of combustion expansion in case of a fire, and the evacuation safety is low because most of the users are not familiar with the building structure [1]. In particular, tourist hotels fall under the building regulations [2] and the fire regulations [3] as accommodation facilities, but when classified in more detail, they are distinguished from general hotels. Since it is larger than a general hotel, the possibility of casualties is relatively high, so it is important to plan for evacuation measures.

The selection criteria for fire alarm methods in the NFSC are too standardized. In the case of the alert at once, when a fire occurs on one floor, a fire alarm sound is emitted on all floors, so the occupants living on all

Manuscript received: November 24, 2021 / revised: November 30, 2021 / accepted: December 7, 2021
Corresponding Author: 119wsu@naver.com
Tel: +82-63-290-1686, Fax: +82-63-290-1478
Associate professor, Dept. of Fire and Disaster Prevention, Woosuk Univ., Korea

floors of the building can recognize the fire situation, which makes it possible to evacuate quickly and immediately. However, the bottleneck in the evacuation stairway is unavoidable. Obviously, the higher the size and height of the building, the more severe the phenomenon will be.

In the case of the priority alarm method, the fire alarm method is applied only to specific fire-fighting objects with 5 or more floors and a total floor area of more than 3,000 m^2. The bottleneck does not appear as serious as in the alert at once, but the evacuation time can be delayed for floors where no fire alarm is generated, and the golden hour may be missed.

In the case of the priority alarm method for four floors directly above, it is applied to high-rise buildings. When a fire occurs one floor, the alarm is only issued to the four floors directly above it, so it can not be applied to other general buildings.

It was decided to apply an alarm method (hereinafter defined as “sequential alarm method”) that was modified from the priority alarm method, judging that it would be possible to show a different aspect by newly introducing and applying methods other than the fire alarm method specified in the NFSC listed above.

In this study, the fire alarm method suitable for the tourist hotel is selected through comparative analysis of the fire alarm method that affects the evacuation time from the moment the evacuation starts to the completion by reproducing the fire situation.

Analyzing existing studies, a previous study [4] conducted an evacuation evaluation by selecting only the priority alarm method instead of the alert at once among the fire alarm methods in the performance-oriented design. In the domestic building environment, it was determined that the priority alarm method could be a fundamental alternative to improving evacuation safety. Another previous study [5-8] selected only the 22^{nd} floors, one of the 32 floors of a high-rise building, and tested the alert at once, priority alarm method, and cross alarm method. As a result, the newly introduced cross alarm method is more effective than other alarm methods results could be derived.

Another study [9] compared and analyzed smoke density, visible distance, and CO concentration using the Pyrosim program and conducted a simulation with a full-faced double envelope structure. It was judged that it is desirable to apply a method that emits preferentially to the fire floor, the immediate upper floor, and the top floor, rather than the uniform priority alarm method according to safety standards.

Another previous study [10] analyzed the acoustic transmission characteristics of the acoustic device of an automatic fire detection facility, a firefighting facility that can evacuate through the auditory perception of occupants in the event of a fire in a high-rise building, to identify the problems of the priority alarm method.

Existing research has selected and applied the priority alarm method, except for the alert at once, and based on the reference floor that does not target all floors of high-rise buildings, the cross-circuit method transformed from priority alarm is derived. The study was conducted in such a way that a fire alarm method was selected through comparative analysis of smoke density, visible distance, and CO concentration using Pyrosim program.

To supplement the limitations of applying an alarm method suitable for the target object by testing it based on one floor rather than applying it to all floors in a specific firefighting object or high-rise building that requires a performance-oriented design, it is necessary to first identify the cause of the bottleneck that occurs during the final evacuation and exit from the building and solve the problem. After that, we would like to draw specific conclusions on how to minimize the bottleneck that occurs during vertical evacuation.

Therefore, in this study, among general buildings that have not been covered in previous studies, the fire alarm method suitable for tourist hotels was analyzed and selected through comparative analysis between the fire alarm method applied in Korea, focusing on the tourist hotel, and the sequential priority alarm method, which is a modification of the priority alarm method.

The purpose of evacuation is to ensure that the occupants of the building have an evacuation time and finally arrive at the ground, which is the evacuation floor, to safely reduce human casualties.

If there is a facility that allows a large number of occupants to evacuate on their own, they can evacuate very effectively, but such an effective system has not yet been developed [11]. Therefore, in this study, by using the evacuation simulation, Pathfinder, to apply the alert at once and the priority alarm method, but also the sequential priority alarm method, a modification of the priority alarm method, we present data for minimizing bottlenecks and deriving the optimal evacuation plan by reviewing the comparative analysis of fire alarm methods set forth the by NFSC Safety Codes in the case of fire in a tourist hotel. Furthermore, it is intended to provide a basis for amending the NFSC in a way that conforms to the structure and environmental conditions of the building rather than the method stipulated in the NFSC.

2. TEST SUBJECT

As shown in **Figure 1**, the experimental subject of this study is a tourist hotel building in Buan, Jeollabuk-do, with one basement level and eight above-ground stories, with a maximum height of 35.50 m and a total floor area of 8,358.75 m^2. Its main use is accommodation (tourist hotels). In this building, there are two places to install an evacuation stair, so the effective width of the stairs is 1,800 mm for the left stair, 1,300 mm for the right stair (1,200 mm or more legal standard), 4,000 mm effective width for the stair landing (1,200 mm or more legal standard), and the stair entrance effective width is 900 mm (legal standard 900 mm or more), and the corridor width is 2,200 mm (legal standard 1,500 mm or more) [12]. All legal standards were properly applied.

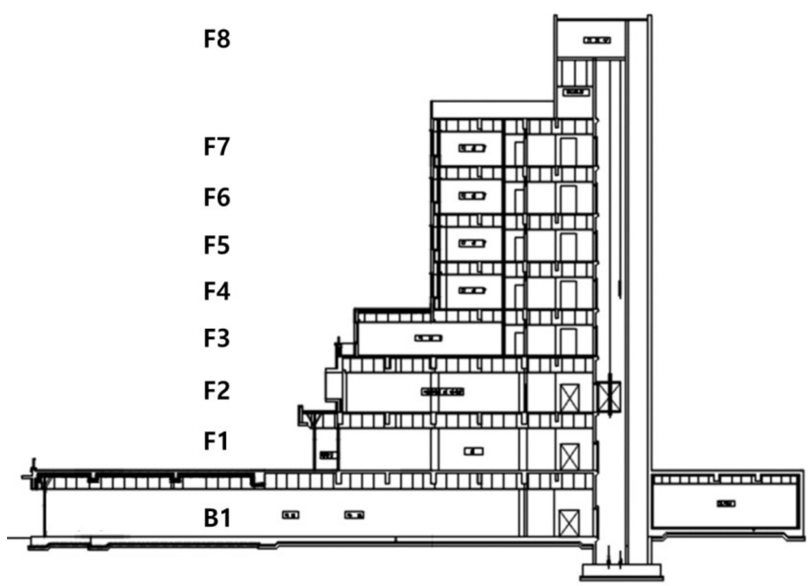


Figure 1. Schematic Diagram

Figure 2 shows the alert at once and priority alarm method stipulated by NFSC202 (emergency broadcasting system) and NFSC203 (automated fire detection system) in this paper, and the priority alarm method for the first four floors applied to the high-rise building stipulated by NFSC604 (high-rise building) was applied, and the sequential priority alarm method, which was modified from the priority alarm method, was applied separately for each scenario. In addition, although the building has an evacuation floor on the 1F basement and 1F due to the difference in site elevation, this study reproduced the situation as only the 1F was an evacuation floor. In the case of accommodation facilities, it is stipulated that at least two simple descending life line or regular descending life line is installed in each room. In the case of this paper, it was assumed that the occupants were evacuated using only the evacuation stairs in two places as evacuation routes.

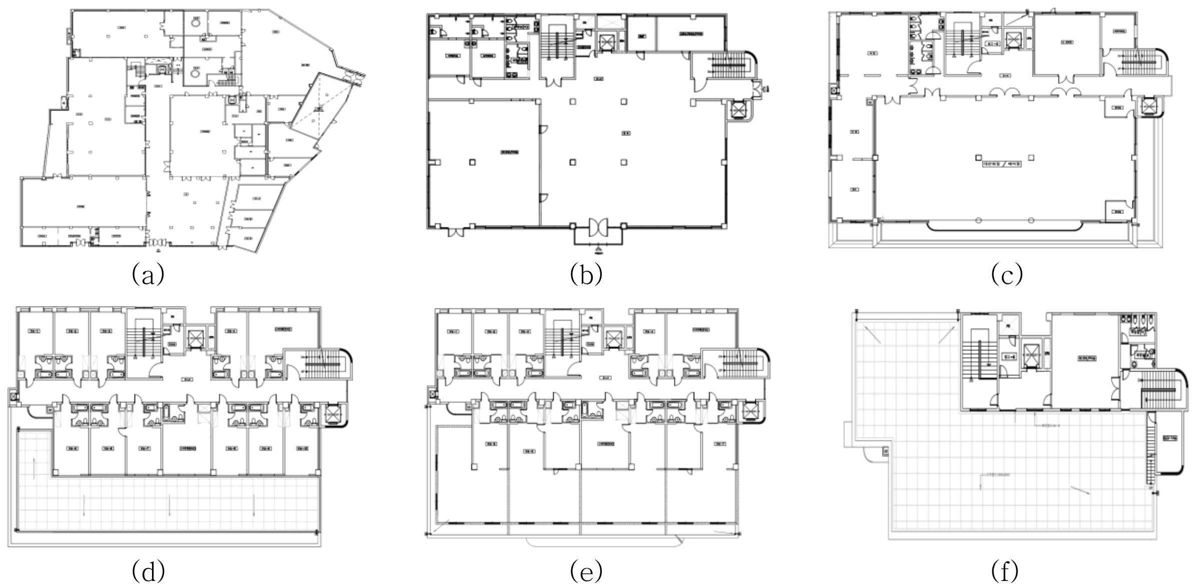


Figure 2. Floor Plan: (a) B1, (b) 1F(Evacuation Floor), (c) 2F, (d) 3F, (e) 4F~7F (f) 8F

3. CONDITIONS FOR EVACUATION SIMULATION

3.1 Model of Fire Alarm System

Although the fire alarm method is classified according to the NFSC regulations, as shown in **Figure 3**, in this study, the number of occupants was calculated by applying the occupant density (18.6 m^2/person) to the floor area of each floor, and input variable values were applied with the distribution and physical condition of the occupants into the Pathfinder program to select the optimal fire alarm method that allows the occupants of the entire building to evacuate effectively according to the difference in alarm methods regardless of the NFSC regulations.

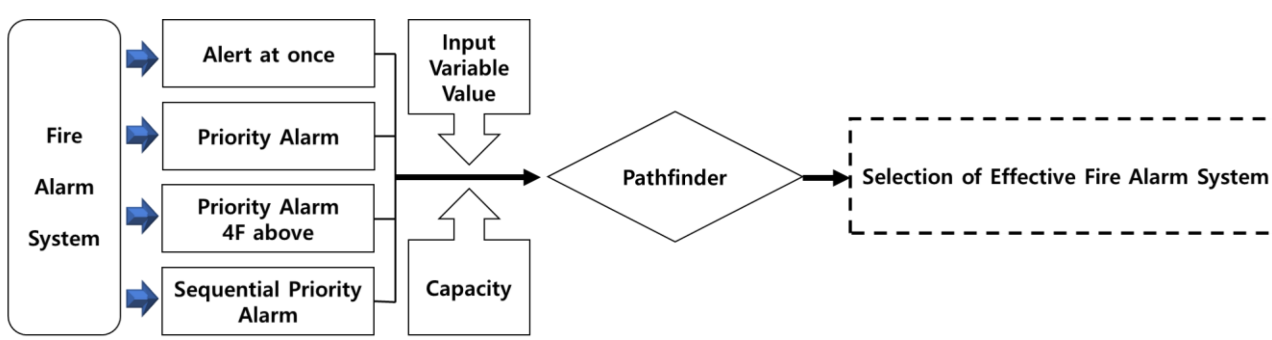


Figure 3. Model of Fire Alarm System

3.2 Scenario Composition

As shown in **Figure 4**, the effective width of the stairway door is set to 0.9 m and 1.4 m, considering the situation in which the fire occurred on the first floor and the occupants of the building are evacuated through the two evacuation stairs connected to the evacuation floor. Similarly, an evacuation evaluation was conducted in consideration of the flow velocity of smoke and bottlenecks in the evacuation stairs for each scenario.

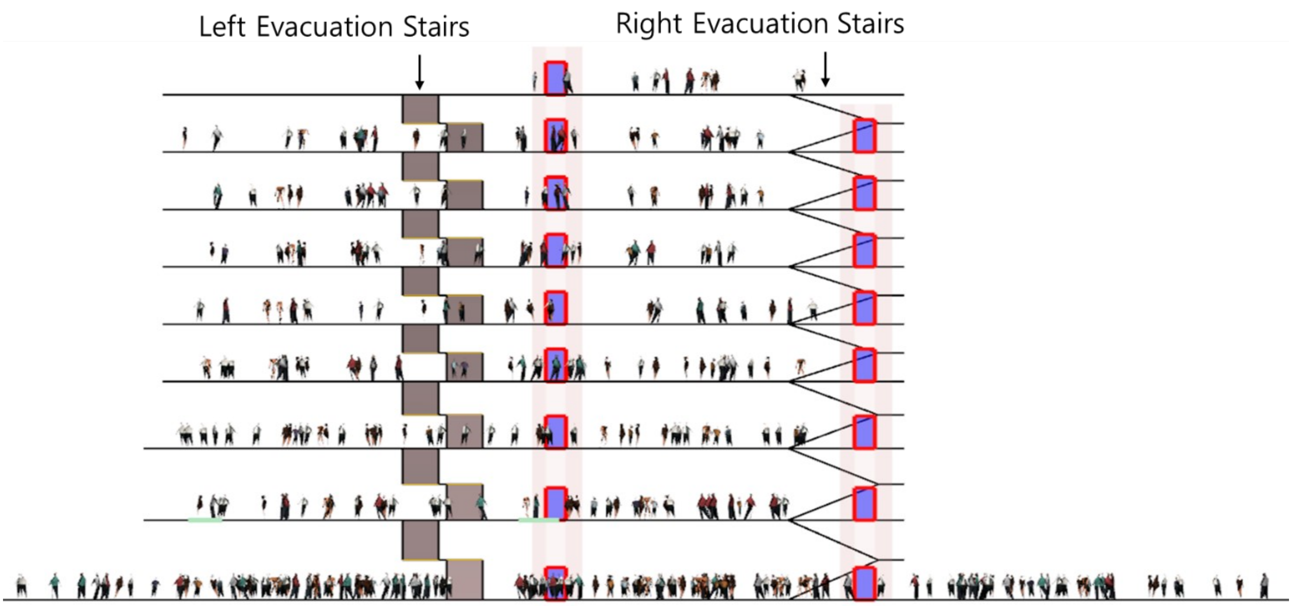


Figure 4. OO Tourist Hotels Evacuation Stairs

Scenario 1 is the most basic fire alarm method, the alert at once. When a fire occurs on a specific floor, the occupants start evacuation at once when the fire alarm sounds on all floors without distinction of floors.

Scenario 2 is a priority alarm method that is applied to a specific firefighting target with a total floor area of more than 3,000 m^2 with 5 or more floors. When this occurs, the occupants of the corresponding floor start evacuation, and when the smoke from the 1F, which is the fire floor, reaches the 2F after 1 second, a fire alarm sound is generated on the 3F, which is the immediately above, and the occupants of the 3F are evacuated. When the smoke reached the 3F after 1 second again, a fire alarm sounds on the 4F, which is the immediately above, and the occupants of the 4F start evacuation. With this setting method, the occupants of the last floor, the 8F, will start evacuation after 6 seconds as a result.

The flow rate of smoke may vary depending on the conditions depending on the outside temperature, such as the stack effect, wind pressure effect, and other equipment effects, and conditions such as smoke windows and fire doors for fire compartments. Considering that the hotel floor height is 4.5 m on the 1F, 4.2 m on the 2F, and 3.6 m on the 3F and above, the flow rate for smoke to reach one floor is assumed to be 1 second excluding the parameters of external factors, smoke window and fire doors. **Table 1** shows the smoke flow rate standards applied to Scenario 2.

Table 1. Flow Rate of Smoke

Velocity according to the direction of smoke (m/s)	Assumed velocity
Horizontal direction: 0.5 ~ 1 Vertical direction: 2 ~ 3 Staircase: 3 to 5	1 Floor/s

Scenario 3 is a priority alarm method for the first 4F above ground. In the event of a fire on the 1F, an alarm sounds preferentially from the 2F to the 5F, which is the four floors directly above, and the occupants of the floor start evacuation, and the setting method is the same as in Scenario 2.

In the case of Scenario 4, as an alarm method modified from the priority alarm method (hereinafter referred to as the sequential priority alarm method), in case of a fire on the 1F, an alarm sound is preferentially generated on the 1F, which is the ignition floor, and the 2F, which is the immediately above to evacuate the occupants of the corresponding floor to the evacuation floor promptly, and then set a time difference to the 3F and 4F after 5 seconds, the 5F and 6F after 10 seconds, and the 7F and 8F after 15 seconds. It was assumed that the floor where the fire alarm sounded continued to emit until the fire was restored. **Table 2** summarizes the above Scenarios.

Table 2. Scenario Configuration

Division	Fire alarm system	Fire alarm sound
Scenario1	Alert at once	In case of fire on the first floor, alarm sounds on all floors
Scenario2	Priority alarm	In the event of a fire on the first floor, an alarm sound is generated preferentially on the first floor, which is the ignition floor, and the second floor, which is the immediately above
Scenario3	Priority alarm 4 floors above	In the event of a fire on the first floor, an alarm sounds preferentially from the first floor, which is the ignition floor, and from the second to the fifth floor, which is the four floors above the ground
Scenario4	Sequential priority alarm	In the event of a fire on the first floor, the alarm sounds up to the second floor, and after 5 seconds, the alarm sounds on each 2 floors

3.3 Evaluation Criteria

In **Table 3**, the required time for evacuation (RSET: Required Safe Egress Time) is within 30 seconds [13] when the detector reaches within the nominal detection concentration range. The time required for effective broadcasting to start automatically was set to be less than 10 seconds [14], and the total evacuation time was set to 40 seconds. The Available Safe Egress Time (ASET) was set to less than 4 minutes as it was used for hotels and lodging purposes specified in the performance-oriented design criteria, and a recorded voice message or a alarm broadcast with trained staff could be provided [15].

Table 3. Evacuation Time Required and Available Evacuation Time Criteria

Cassification	Contents	Criteria
RSET	After 30 seconds of fire detector operation time Emergency broadcasting facility speaker broadcasting start in 10 seconds Evacuation starts after 40 seconds	-
ASET	Hotel, lodging use (The occupants are not familiar with the building's interior, alarms, and escape routes, and may be sleeping)	less than 4 minutes

3.4 Calculation of Capacity

In **Table 4**, when calculating the number of occupants, the floor area of corridors, stairs and toilets was not included, and the number of occupants to the nearest decimal point was rounded off [16].

The occupant density (18.6 m^2/person) was applied to the space of the floor area of the tourist hotel, and the number of occupants on each floor was calculated to place a total of 453 people.

Table 4. Criteria for Calculating the Number of Occupants

Purpose of use	Floor	Floor area (m^2)	m^2/person	Capacity (person)
Tourist Hotels	B1F	3,486.60	18.6	188
	1F	860.51		47
	2F	848.69		46
	3F	767.43		42
	4F ~ 7F	555.53		120(30×4 floors)
	8F	173.40		10
Total		8,358.75		453

3.5 Input Variable Value

According to the 2021 Jeollabuk-do Population Proportion Survey by gender and age, the ratios were set separately for children (0-9 years old) and adolescents (10-19 years old). As shown in **Table 5**, children and adolescents were combined as children, and the range of children was limited to the ages of 1st to 6th grade in elementary school.

Height was judged to be an unnecessary item for evacuation, so it was excluded from the input value and the walking speed for the disabled was 0.78 m/s when using crutches, and 0.87 m/s when using a wheelchair. However, the disabled who use a wheelchair were also excluded from the input value due to evacuation stairs scenario case.

Table 5. Occupant Distribution and Physical Condition

Occupant composition	Age (years)	Percentage(%)	Shoulder width (cm)	Applicable walking speed (m/s)
Senior citizen	60+	27.61	36.7	0.83
Adult male	20~59	25.87	39.8	1.19
Adult female	20~59	23.74	35.8	1.10
Child	8~13	15.47	30.1	1.0
Disabled	20~59	7.31	37.8	0.78

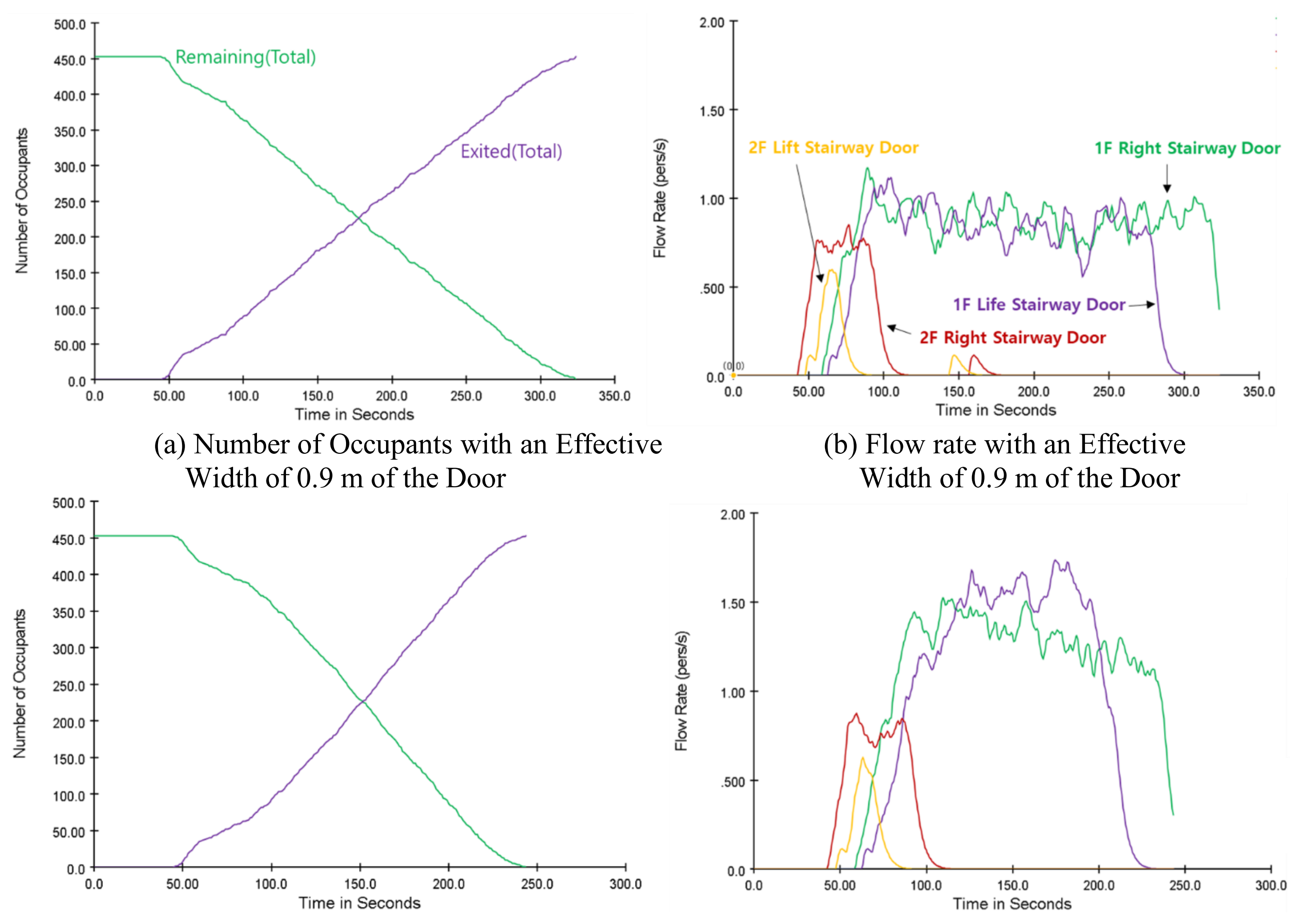
4. PATHFINDER RESULTS

4.1 In Case the Effective Widths of the Evacuation Stair Doors in 2 Places on Each Floor are 0.9 m and 1.4 m

4.1.1 Scenario 1

Through the evacuation simulation, the total time for all occupants completed evacuation after 40 seconds of evacuation using the evacuation stairs is 323.8 seconds when the effective width of the evacuation staircase door is 0.9 m, and 243.5 seconds in case of 1.4 m. The section where the bottleneck occurs the most is the 1st and 2nd floors. In the case of the 1st floor, the basement has the largest number of occupants. It occurs when the occupants use the evacuation stairs to the 1st floor at the same time. As all floors started evacuating at once, it gradually started to stagnate on the second floor, and the concentration between the occupants coming up from the basement floor and the occupants coming down from the upper floors caused a serious bottleneck. At the intersection of **Figure 5(a)**, 227 people completed evacuation of the total number of occupants in an average of 178.7 seconds, and at the intersection of **Figure 5(c)**, 227 people completed evacuation in an average of 149.5 seconds. In **Figure 5(b)**, the flow rate is 0.88 (pers/s) on the average for the right stair on the first floor, 0.84 (pers/s) for the average on the left stair on the first floor, and **Figure 5(d)** shows the flow rate on the average for the right stair on the first floor 1.28 (pers/s), the left stair on the first floor showed an average of 1.24 (pers/s).

The phenomenon shown in Figure 5 represents the number of occupants passing through the door in the time required as in **Figure 5(a)** and **(c)** according to the effective width of the door of the evacuation stair, and the bottleneck phenomenon occurs the most as shown in **Figure 5(b)** and **(d)**. It can be seen that the flow rate of the stair entrances on the first and second floors of the first and second floors is significantly different.



(a) Number of Occupants with an Effective Width of 0.9 m of the Door

(b) Flow rate with an Effective Width of 0.9 m of the Door

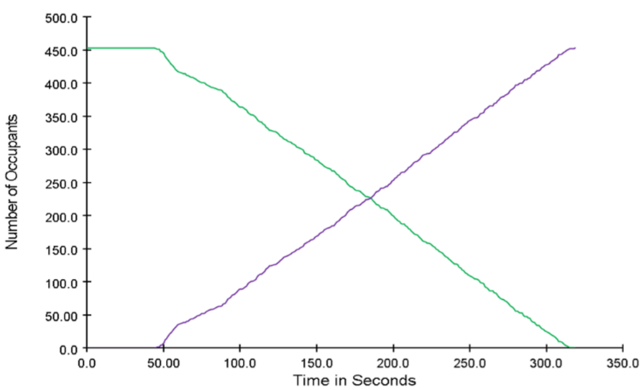
(c) Number of Occupants with an Effective Width of 1.4 m of the Door

(d) Flow Rate with an Effective Width of 1.4 m of the Door

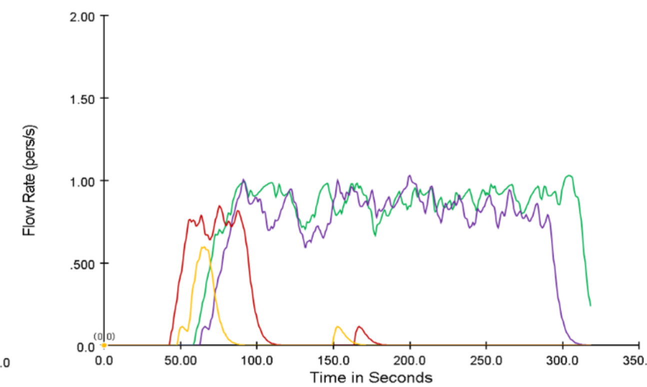
Figure 5. Alert at Once

4.1.2 Scenario 2

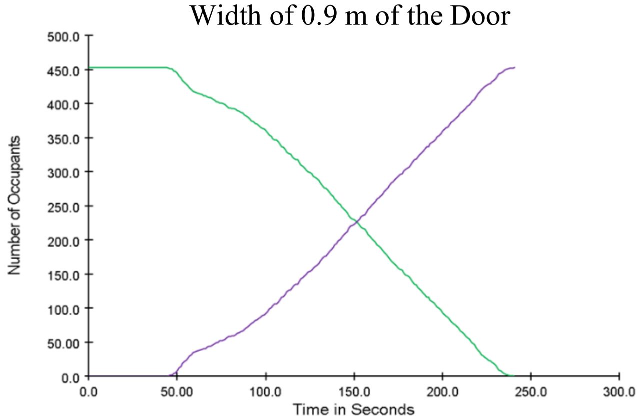
The time for the total number of occupants to complete the evacuation 40 seconds after the start of evacuation was 318.5 seconds when the effective width of the evacuation stair door was 0.9 m, which was 5.3 seconds shorter than the alert at once. In the case of an effective width of 1.4m, it was shortened by 3.0 seconds to 240.5 seconds. At the intersection of **Figure 6(a)**, 227 occupants completed the evacuation out of the total number of occupants in an average of 181.5 seconds, and at the intersection of **Figure 6(c)**, 227 people completed evacuation in an average of 148.3 seconds. In **Figure 6(b)**, the flow rate is 0.88 (pers/s) on the average for the right stair on the first floor, 0.82 (pers/s) for the left stair on the first floor, and **Figure 6(d)** shows the average flow rate for the right stair on the first floor 1.20 (pers/s), the left stair on the first floor showed an average of 1.25 (pers/s). If judged by the ASET standard, it is inappropriate, but when only the alert at once and the priority alarm method were compared, as a result, the priority alarm method was found to be excellent.



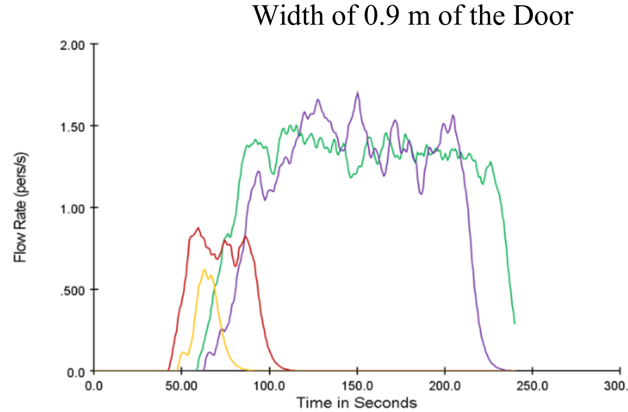
(a) Number of Occupants with an Effective Width of 0.9 m of the Door



(b) Flow Rate with an Effective Width of 0.9 m of the Door



(c) Number of Occupants with an Effective Width of 1.4 m of the Door



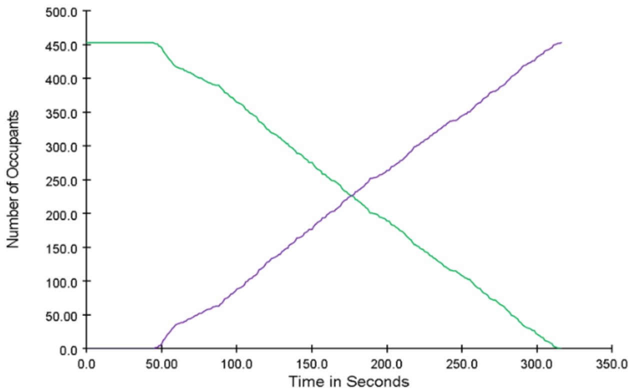
(d) Flow Rate with an Effective Width of 1.4 m of the Door

Figure 6. Priority Alarm

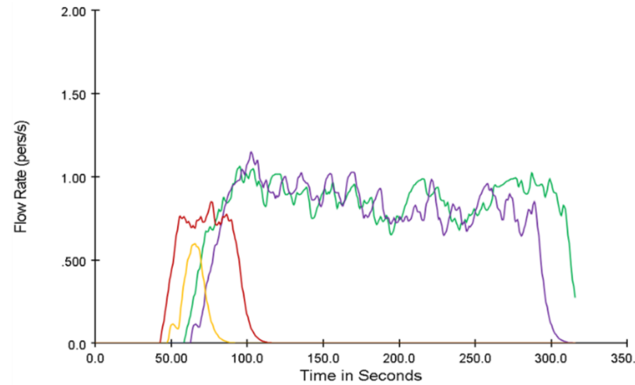
4.1.3 Scenario 3

Scenario 3 is a method that cannot be applied in NFSC, but as a result of applying the priority alarm method for the first four floors to a tourist hotel building, the time when the total number of occupants completed evacuation is 316.0 seconds when the effective width of the evacuation stair door is 0.9 m, 236.8 seconds in the case of the effective width 1.4 m. At the intersection of **Figure 7(a)**, 227 people completed evacuation in an average of 178.5 seconds, and at the intersection of **Figure 7(c)**, 227 people completed evacuation in an average of 146.5 seconds. In **Figure 7(b)**, the flow rate is 0.87 (pers/s) on the average for the right stair on the

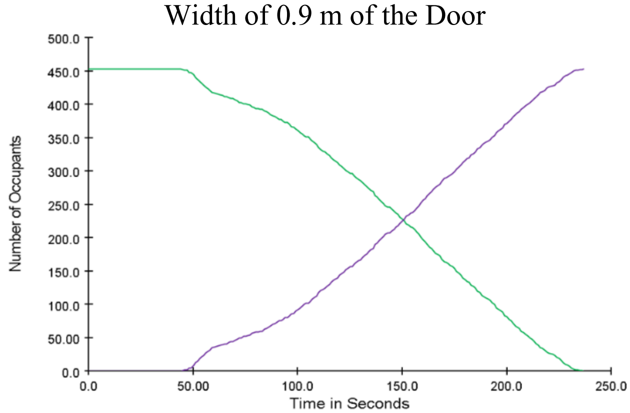
1st floor, 0.84 (pers/s) for the average on the left stair on the 1st floor, and **Figure 7(d)** shows the flow rate on the average for the right stair on the 1st floor 1.31 (pers/s), the left stair on the first floor showed an average of 1.27 (pers/s). As a result, it was found that when the priority alarm method for the first four floors, which cannot be applied to a building to which the priority alarm method should be applied, was measured 3.7 seconds shortened based on the effective width of the evacuation stairs of 1.4 m.



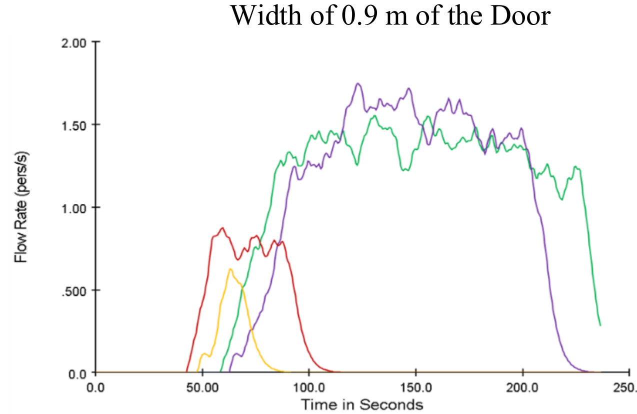
(a) Number of Occupants with an Effective Width of 0.9 m of the Door



(b) Flow Rate with an Effective Width of 0.9 m of the Door



(c) Number of Occupants with an Effective Width of 1.4 m of the Door

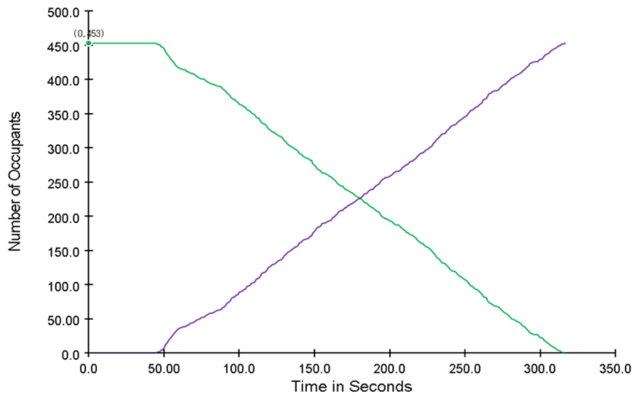


(d) Flow Rate with an Effective Width of 1.4 m of the Door

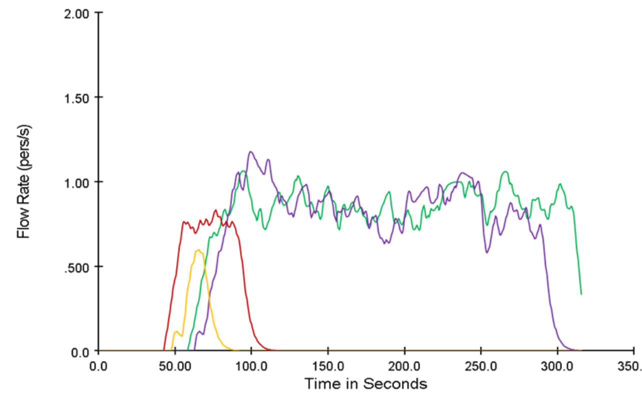
Figure 7. Priority Alarm 4 Floors Above

4.1.4 Scenario 4

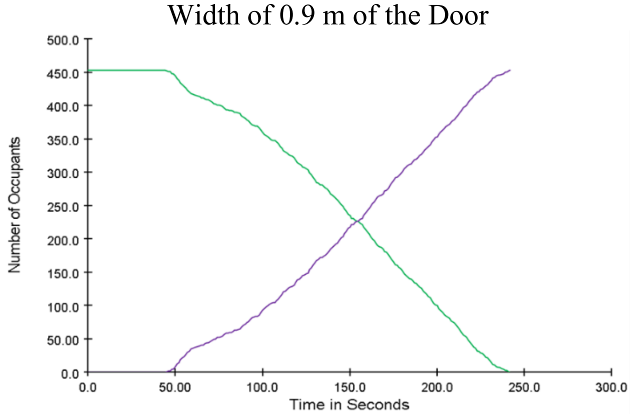
As shown in **Figure 8**, the total number of occupants completed evacuation was 316.3 seconds when the effective width of the evacuation stair door was 0.9 m, and 241.5 seconds when the effective width was 1.4 m. Similar results were obtained with no significant difference as in all scenarios except for Scenario 3. At the intersection of **Figure 8(a)**, 227 people completed evacuation in an average of 179.4 seconds, and at the intersection of **Figure 8(c)**, 227 people completed evacuation in an average of 149.9 seconds. In **Figure 8(b)**, the flow rate is 0.86 (pers/s) on the average for the right stair on the first floor, 0.85 (pers/s) for the average on the left stair on the first floor, and **Figure 8(d)** shows the flow rate on the average for the right stair on the first floor 1.26 (pers/s), the left stair on the first floor showed an average of 1.20 (pers/s). Therefore, it can be seen that the method applied to Scenario 4 has no significant effect.



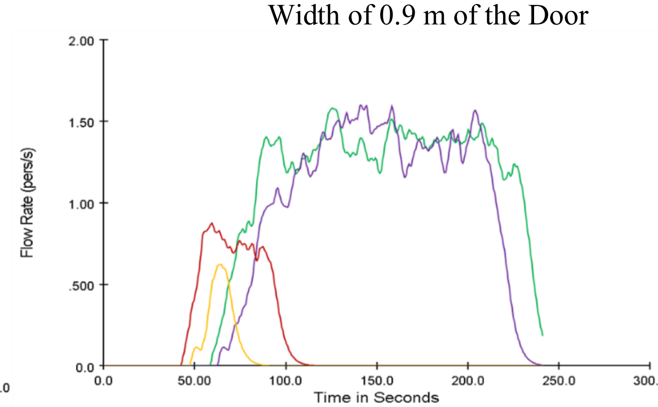
(a) Number of Occupants with an Effective Width of 0.9 m of the Door



(b) Flow Rate with an Effective Width of 0.9 m of the Door



(c) Number of Occupants with an Effective Width of 1.4 m of the Door



(d) Flow rate with an Effective Width of 1.4 m of the Door

Figure 8. Sequential Priority Alarm

4.2 Comparison of Evacuation Time

As shown in **Table 6**, when the final evacuation time required for each scenario was analyzed, it was found that the priority alarm method for the 4 floors above scenario 3 showed more effective results in both the case of 0.9m and 1.4m of the effective width of the evacuation stair door.

Table 6. Final Evacuation Time by Scenario

Classification	The effective width of the evacuation stair door is 0.9m				The effective width of the evacuation stairway door is 1.4m			
Configuration	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Contents	alert at once	Priority alarm	Priority alarm 4 floors above	Sequential priority alarm	alert at once	Priority alarm	Priority alarm 4 floors above	Sequential priority alarm
ASET	less than 240				less than 240			
Final evacuation time (s)	323.8	318.5	316.0	316.3	243.5	240.5	236.8	241.5
Judgment	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable	suitable	unsuitable

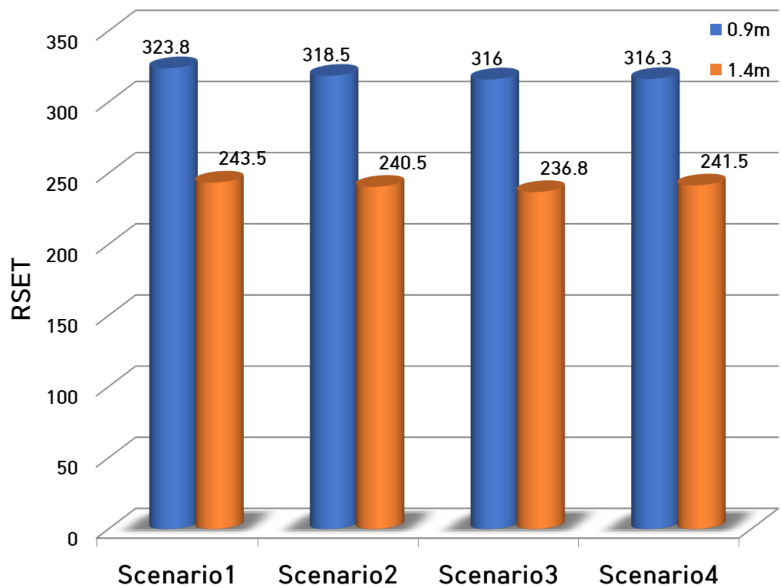


Figure 9. Final Evacuation Time by Scenario

5. CONCLUSION

This study analyzed the issue of selecting a fire alarm method based on the measurement of the evacuation time required through the evacuation stairs with an effective width of 0.9 m and 1.4 m for two evacuation stairs, targeting the 00 tourist hotel in Buan, Jeollabuk-do, and finding a solution. Ultimately, the rationale for the revision of the NFSC was presented.

First, as a result of performing evacuation simulation by applying the fire alarm method prescribed in NFSC and the sequential alarm method modified from the priority alarm method, the time was not significantly shortened. The results, however, showed that the evacuation time of the priority alarm method for the first four floors was faster than the priority alarm method that should be applied to the specific fire-fighting object. Therefore, it is necessary to take measures to select a fire alarm method suitable for the structure and environmental conditions of the building rather than applying the uniform NFSC regulations.

Second, in the space causing congestion for the tourist hotel, the bottleneck occurred at the exit of the evacuation stairwell on the 1st and 2nd floors. With the effective width of the door, the closer the floor was to the ground, the more congestion increased, and the flow rate at the exit decreased. Therefore, when designing a tourist hotel, it should be considered to avoid congestion due to overcrowding by giving enough effective width of the exit door to the evacuation stairwell, and also to control the flow of evacuation by adjusting the number of occupants according to time intervals.

As a limitation of this study, the speed of smoke flow to the upper floors was not verified. The effect of smoke during a fire is the biggest cause of casualties at fire sites, and its importance is high enough that suffocation by smoke accounts for 80-90% of all deaths.

As a future research project, it is necessary to apply the diffusion and movement of smoke in case of fire to the evacuation time through fire simulation.

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