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A Study on the Effects of All-in-one Automatic Fire Shutters Installed in High School on Evacuation Time

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Abstract

This study analyzed the effects of the all-in-one automatic fire shutter (hereinafter referred to as "all-in-one shutter") installed along the fire compartment in a five-story high school building on the evacuation time by using the Pathfinder simulation program. When the all-in-one shutter was added as a new variable, the evacuation time was delayed, indicating insufficient evacuation safety. The evacuation time exceeded the appropriate standard when the evacuation exit was designated to the students in the present state of being placed on the 2nd, 3rd, and 4th floors and the all-in-one shutter was activated. When students were placed on the 1st, 2nd and 3rd floors under the same conditions, the evacuation time was also greatly exceeded. However, when the width of the entrance was set to 130cm, the evacuation time was almost the same as when the all-in-one shutter was not installed. In high-rise school buildings, the bottleneck caused by all-in-one shutters is becoming a major factor in evacuation barriers. To ensure the evacuation safety of school buildings, it has been judged that evacuation education and training to predict the evacuation time required through the all-in-one shutter entrance and induce an evacuation procedure suitable for the standard evacuation time should be carried out in parallel. The implications of this study and suggestions for effective fire compartments and follow-up studies were discussed.

Keywords: *All-in-one Automatic Fire Shutter, Pathfinder, Evacuation Time, High School*

1. INTRODUCTION

1.1 The Need for Research

Before 「the Act on the Safety and Maintenance of Educational Facilities」(hereinafter referred to as the Educational Facilities Act)" came into force, about 75.4% of educational facilities were excluded from legal safety management as they were managed by other laws such as 「the Facilities Safety Act」. It was difficult

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to systematically manage and inspect facilities in preparation for aging facilities and disasters [1]. It is pointed out that about 190 fires continue to occur in schools every year [2], and various disasters and safety accidents such as the Gyeongju and Pohang earthquakes and the collapse of the Sangdo kindergarten building continue to occur, which threatens the safety of students. There has been a growing concern about educational facilities. However, as the Education Facilities Act comes into effect from 2020, safety inspections are mandatory for all educational facilities at least twice a year, and when defects are found, measures such as repair and reinforcement must be taken [1].

The all-in-one automatic fire shutter (hereinafter referred to as "all-in-one shutter") installed to prevent the spread of fire and ensure evacuation safety can't be expected. In most schools, fire protection partitions are set for every 1,000m^2 of floor area and integral shutters are installed [3]. At school sites, safety inspection of the integrated shutter facility is conducted to check whether there is an abnormality in the fire shutter interlocking controller. However, considering the specificity of the all-in-one shutter that blocks the escape passage, closing the fire shutter and checking whether it is damaged is not enough. In consideration of the special situation where the all-in-one shutter is lowered and a part of the evacuation passage is blocked, a performance-oriented evacuation safety inspection is also necessary to check the evacuation time.

Although the all-in-one shutter is effective in minimizing combustion and preventing the spread of fire, an entrance with an effective width of 0.9m or more and an effective height of 2m or more installed in the all-in-one shutter may delay the evacuation time and hinder evacuation activities. Securing a safe escape route in case of fire is an important prerequisite for reducing potential damage. For a more effective safety inspection of the all-in-one shutter, it is necessary to estimate the evacuation time in consideration of the school environment and the pros and cons of the all-in-one shutter, and to check whether appropriate evacuation safety education and fire drills are provided. However, the research on evacuation time prediction by considering the width of the all-in-one shutter entrance installed in the school as an evacuation simulation variable has not been reported yet, so research and countermeasures in this field are needed.

1.2 Prior Research Analysis and Research Purpose

Looking at the previous studies on the safety of evacuation of educational facilities in case of fire, studies have been mainly conducted on the evacuation exit and classroom arrangement that affects the evacuation time delay. However, studies on the effect of evacuation when the all-in-one shutter is lowered on the evacuation passage are insufficient.

Lee et al. [4] analyzed an efficient class floor arrangement plan for securing evacuation safety in schools using the Pathfinder simulation program. Considering the safety aspect of evacuation in case of fire, when arranging students in a high-rise school building, it is effective to arrange them from the bottom floor, and it was found that the evacuation time was shortened by designating an evacuation exit. Choi and Kong [5] evaluated the evacuation safety of high school buildings by analyzing the effects of stairs and ramps on evacuation using an evacuation simulation program. It was reported that the evacuation time was shortened when using a slope that is more gentle than stairs and arranging an appropriate classroom around the evacuation exit. Lim [6] presented the results of a study on the evacuation passage width affecting evacuation safety in elementary schools with the latest automatic fire extinguishing systems using fire simulation. For proper evacuation in both directions, it is necessary to secure a wide evacuation path, and when an evacuation path is closed due to the operation of an automatic fire door, young students who are not familiar with this can easily get excited or lose their temper and cause an airport state, so the necessity of periodic education and training is emphasized.

In previous studies [4-6], the evacuation route, calculation and characteristics of people, walking speed,

density of people, and evacuation start time were selected as input variables for evacuation simulation for school evacuation safety analysis, but the width of the all-in-one shutter entrance was not considered. The purpose of this study is to investigate how the entrance installed in the all-in-one screen automatic fire shutter made of fire-resistant fiber affects the evacuation time. According to the amendment of Article 46 of the Building Act Enforcement Decree [3], the term all-in-one shutter is no longer used, but the already installed all-in-one shutter can follow the previous regulations. This study aims to differentiate it from previous studies by analyzing how the all-in-one shutter entrance with an effective width of 0.9m or more and an effective height of 2m or more, installed in schools, affects the evacuation time. To this end, the purpose of this study was to analyze the evacuation time for a five-story high school building with all-in-one shutters installed. This will help to induce an evacuation procedure suitable for the evacuation time by estimating the evacuation time required through the entrance installed in the all-in-one shutter using the evacuation simulation. In addition, it will provide useful data for fire drills and education using all-in-one shutter entrances and help analyze the effectiveness of evacuation routes.

2. BODY

2.1 Evacuation Simulation for Performance-Oriented Design

As the flow of fire safety regulations generally shifts to performance-oriented design, the evacuation plan is also changing from uniform items such as evacuation stairs or ramp installation standards to items such as evacuation routes and evacuation time [7]. In general, the analysis for human safety from fire is mainly related to the spatial composition and movement of the building, and the evacuation simulation is applied to analyze the effectiveness of the evacuation movement by evaluating how long it takes for evacuation and where the congestion section will occur.

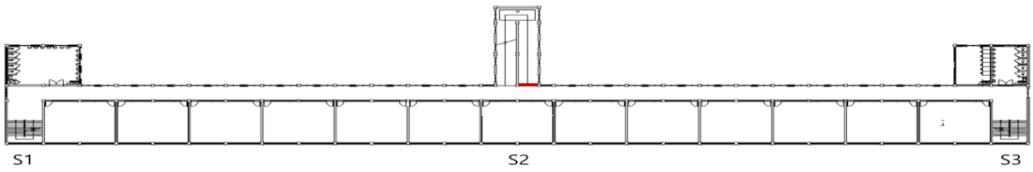
The Pathfinder used to perform the evacuation simulation in this study is an evacuation simulation program developed by Thunderhead [8] in 2009. It can help guide the optimal evacuation procedure by checking the degree of congestion and delay in all routes, such as in the hallway or corridor [9].

2.2 Target Building and All-in-one Shutter

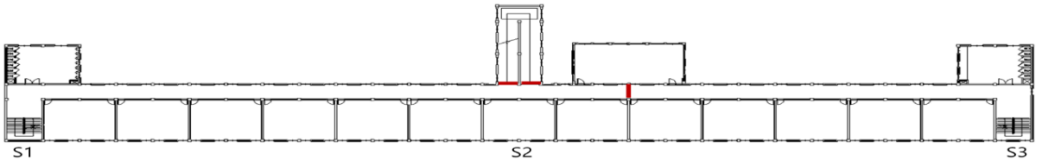
As the target school building is shown in Figure 1, it is a five-story building for a boys' high school and consists of a total of 30 classrooms on the 2nd, 3rd, and 4th floors, as well as special rooms such as the administrative office, the principal's office, self-study room, science room and English room. This building has a floor height of 3.6m, a width of 126m, and a length of 18m. A 2.5m wide and 12m long ramp and a 2.5m wide hallway are installed in the center of the building. It satisfies the appropriate standard corridor width of 2.4m or more as suggested in 「Article 15 Paragraph 2 of the Rules on Standards for Evacuation and Fire Protection Structures for Buildings」. At the left and right ends, 2.65m in length, 2m in width, and 10 steps based on the landing are installed. The width of the central exit is 9m, and the width of the left and right exits of the building is 2.7m, respectively. The target school building recently installed an all-in-one shutter with a width of 100cm and a height of 200cm at the entrance.

The floor area of the classroom is 67.5m2. Considering the standard for calculating the number of people 1.9m2/person according to 「Performance-oriented design methods and standards for firefighting facilities, etc.」[3], the class with the number of people in the classroom with the largest number of students being 32(2.1m2/1 person) and the smallest number of students being 20(3.4m2/1 person) met the calculation criteria.

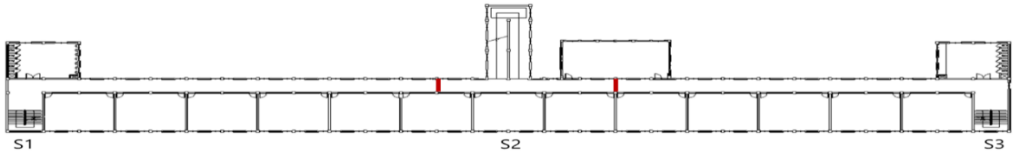
The all-in-one shutter refers to an all-in-one automatic fire shutter installed in an entrance for evacuation [1]. As shown in Figure 2, the all-in-one shutter installed along the fire compartment has a 100cm wide entrance.



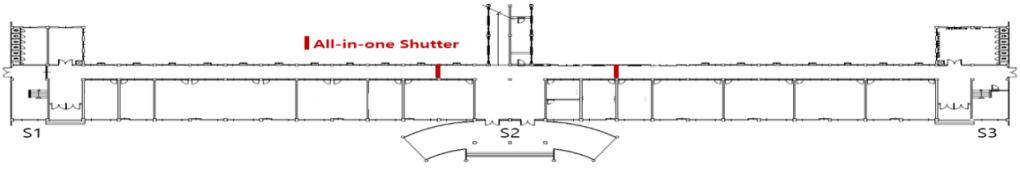
(d) 5th floor floor plan



(c) 3rd and 4th floor floor plan



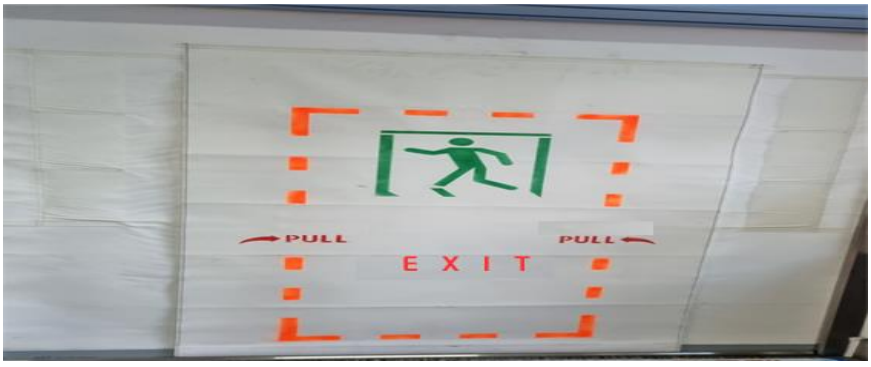
(b) 2nd floor floor plan



(a) 1st floor floor plan

Figure 1. Structural floor plan of the main building in △△ high school and the installation location of the all-in-one shutter

(a) All-in-one shutter



(b) All-in-one shutter entrance

Figure 2. All-in-one automatic fire shutter

2.3 Scenario Setting and Evacuation Time Analysis

Scenarios for the same school analyzed in this study were analyzed by two scenarios that were judged to be appropriate in the evacuation time for six hypothetical scenarios by Lee et al. [4]. In addition, the evacuation time was measured by adding an all-in-one shutter as a new variable to each scenario.

As shown in Figure 1, it was set to evacuate using the left exit(S1), the central ramp exit(S2), and the right exit(S3) of the building. The evacuation time was defined as the time when all the students finally passed through exits S1, S2, and S3 on the first floor. The exit designation criteria for evacuation considered the proximity of the left and right stairs and the central ramp. The three classes close to the left and right stairs were set to evacuate using the exit of the left and right stairs, respectively, and the central five classes including the school office were set to evacuate using the central ramp.

Scenario 1 is the current classroom layout of the school. The principal and administrative staff are on the 1st floor. Students, teachers, and administrative assistants are on the 2nd, 3rd and 4th floors, and the special room teacher resides on the 5th floor. In case of evacuation, an exit is designated. Scenario 2 is a plan to minimize evacuation travel time. Students and office are placed on the 1st, 2nd and 3rd floors, and administrative staff are placed on the 4th floor. The teachers in charge reside in the special room on the 5th floor, and the exit is designated for evacuation. The reason for placing the special room on the 5th floor is to minimize damage in case of fire and explosion caused by hazardous materials in the science lab. A total of 786 students were assigned, 258 first-year students, 265 second-year students, and 263 third-year students. The scenario configuration in which the all-in-one shutter is installed in each scenario is presented in Table 1.

Table 1. Scenario configuration

Scenario conditions Classroom and staffing by floor N=786 (Students: 711, Staff: 75)							
				Left	Mid	Right	TTL
Scenario	Exit	All-in-one shutter installation and number	Floor	Number of classrooms (Number of people)	Number of classrooms (Number of people)	Number of classrooms (Number of people)	Number of classrooms (Number of people)

Scenario 1	Desig-nation	Installation	1pc	5	1(1)	1(1)	1(1)	3(3)
			3pcs	4	3(64)	5(112)	3(72)	11(248)
			3pcs	3	3(67)	5(133)	3(72)	11(272)
			2pcs	2	3(71)	5(109)	3(71)	11(251)
			2pcs	1	-	1(12)	-	1(12)
		TTL			10(204)	14(355)	10(227)	34(786)
Scenario 2	Desig-nation	Installation	1pc	5	1(1)	1(1)	1(1)	3(3)
			3pcs	4	-	1(12)	-	1(12)
			3pcs	3	3(64)	5(112)	3(72)	10(248)
			2pcs	2	3(66)	5(134)	3(72)	10(272)
			2pcs	1	3(64)	5(118)	3(69)	11(251)
		TTL			10(204)	14(355)	10(227)	34(786)

If the simulation evacuation time results without all-in-one shutters are summarized by scenario, in the case of Scenario 1, where students are placed on the 2nd, 3rd, and 4th floors, evacuate by designating an exit rather than when evacuating without designating an evacuation exit, evacuation time was found to be 219.0 seconds. In the case of Scenario 2, when an evacuation exit was designated, the evacuation time was shorter than that of Scenario 1, 186.0 seconds [4]. Currently, the all-in-one shutter with an 100cm wide entrance is installed. For each scenario, the evacuation time according to the width of the entrance was determined by setting 90cm as the minimum entrance width in accordance with the provisions of the Enforcement Decree of the Building Act [3] and increasing it by 10cm intervals. The evacuation time was compared and analyzed by increasing it to a width of 130cm, which requires a similar appropriate evacuation time when an all-in-one shutter is installed.

2.4 Input Variables and Input Values

In this study, Korean human body size [10] and average walking speed of adults [4] were applied as an input variable reflected in the Pathfinder evacuation simulation. The evacuation start time [11] required to detect a fire and prepare students for evacuation according to the fire notification was set to 30 seconds. Specific input variables and input values are presented in Table 2.

Table 2. Input variable and input value

Input variable	Input value	
Evacuation start time	After 30 seconds evacuation starts	
Walking speed	1.19m/s	
Shoulder width (cm)	1st Grade(17years old)	39.1
	2nd Grade(18years old)	39.3
	3rd Grade(19years old)	39.8
Height (cm)	1st Grade(17years old)	172.6
	2nd Grade(18years old)	173.0
	3rd Grade(19years old)	173.1

3. RESULTS AND ANALYSIS

3.1 Evacuation Time and Travel Distance According to the Width of the Entrance

In Scenario 1, where the current students are placed on the 2nd, 3rd, and 4th floors and set in a real situation, the evacuation time was measured to be 219.0 seconds when an evacuation exit was designated and an all-in-one shutter was not installed. In the case of Scenario 2, students were placed on the 1st, 2nd, and 3rd floors under the same conditions, and the evacuation time was 186.0 seconds, which resulted in a 33.0 second faster evacuation time than Scenario 1. In Scenarios 1 and 2, when the all-in-one shutter was installed and the width of the entrance was applied as a variable, the evacuation time was the longest when the width of the entrance was 90cm, and each time the width increased by 10cm, the evacuation time was shortened accordingly. In particular, in the case of Scenario 2, it can be seen that when the width of the entrance is set to 130cm, the evacuation time is almost the same as when the all-in-one shutter is not installed.

In addition, in the case of Scenario 1, the movement distance of at least 18.5m and maximum of 151.7m was measured according to whether or not the all-in-one shutter was installed for each scenario. In the case of Scenario 2 under the same conditions, a minimum movement distance of 12.6 m to a maximum of 143.6m was measured. However, when the all-in-one shutter was installed, the maximum movement distance was increased in both scenarios 1 and 2, and when the entrance width of the shutter was increased from 90cm to 130cm, the movement distance decreased according to the enlarged width. Table 3 shows the evacuation time and travel distance measurement results according to the width of the entrance of the all-in-one shutter for each scenario.

Table 3. Evacuation time and movement distance measurement results according to the width of the all-in-one shutter entrance

Scenario	Entrance width (cm)	Final evacuation time(s)	Movement distance (m)		
			Min	Max	Ave
Scenario 1	Not installed	219.0	18.5	151.7	77.0
	90	321.3	18.5	215.9	80.5
	100	305.5	18.5	213.0	79.7
	110	298.5	18.5	206.7	77.5
	120	276.0	18.5	159.8	77.3
	130	267.5	18.5	153.1	77.1
Scenario 2	Not installed	186.0	12.6	143.6	55.6
	90	228.5	12.6	194.8	56.4
	100	216.5	12.6	166.4	55.9
	110	208.0	12.6	150.5	55.8
	120	192.3	12.6	150.4	55.7
	130	186.3	12.6	150.3	55.6

3.2. Bottleneck According to the Width of the All-in-one Shutter Entrance

From Table 3, it can be seen that the evacuation time increases when the all-in-one shutter is activated in Scenarios 1 and 2. For each scenario, the longest evacuation time was measured when the width of the all-in-one shutter entrance was 90cm, and the evacuation time was shortened when the entrance width was increased. In order to check the change in evacuation time according to the width of the entrance of the all-in-one shutter,

a trap to measure the population density was installed on the central ramp on the 3rd floor where the all-in-one shutter was installed, and the population density according to the bottleneck was measured.

In the case of Scenario 1, the population density was highest when the all-in-one shutter was not installed and it was 60 seconds after the evacuation started. Based on this, the results of analyzing the population density of the central ramp on the 3rd floor where the trap is installed when the width of the all-in-one shutter entrance increases are presented in Figure 3 and Figure 4.

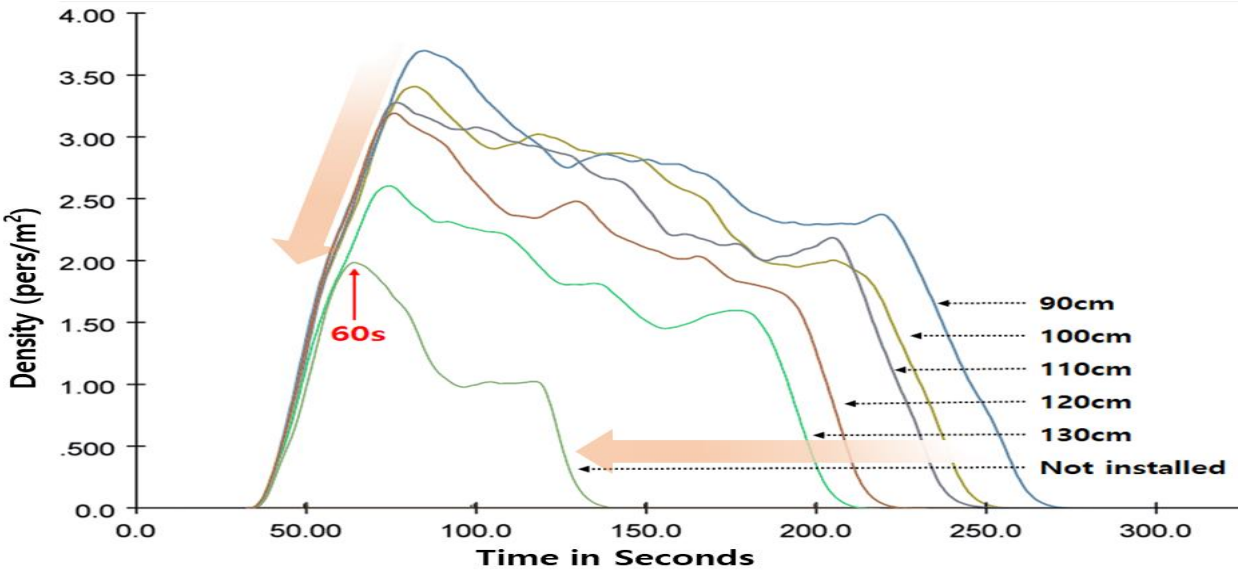


Figure 3. 3rd Floor central ramp entrance population density graph for scenario 1

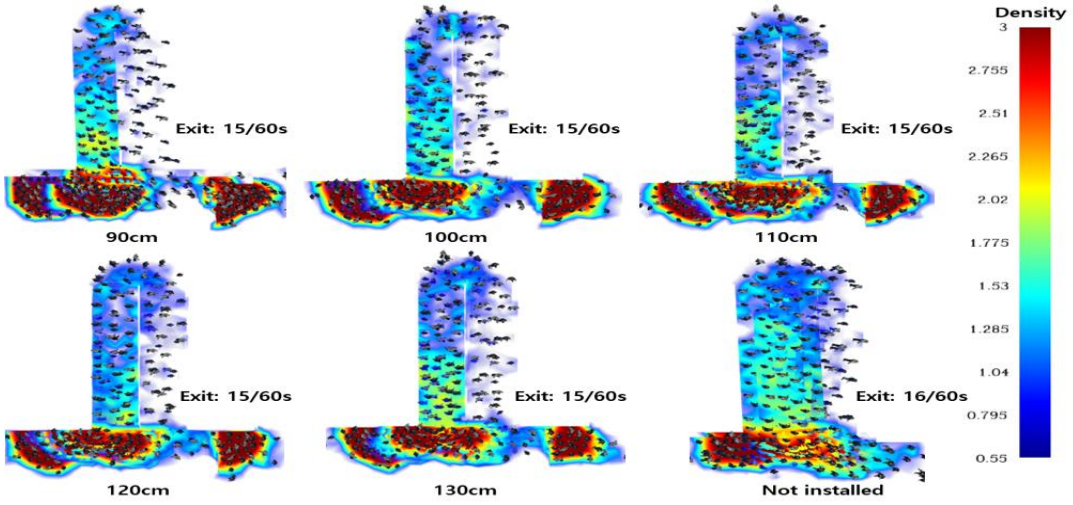


Figure 4. Scenario 1 - population density projection of the central ramp after 60 seconds of evacuation

Looking at Figure 3, as the width of the entrance decreased, the population density increased and the evacuation time increased. Looking at Figure 4, the number of people who completed the evacuation at 60 seconds after the evacuation started was the same as 15 people, but the most severe bottleneck was when the entrance of the all-in-one shutter installed on the central ramp on the 3rd floor was 90cm. For this reason, the evacuation time was also measured as the longest at 321.3 seconds. It can be seen that as the width of the entrance of the all-in-one shutter increases, the bottleneck is reduced and the evacuation time is shortened.

In the case of Scenario 2, the population density was highest at 68 seconds after evacuation started when no all-in-one shutters were installed. Based on this, the results of analyzing the population density of the central ramp on the 3rd floor where the trap is installed when the width of the all-in-one shutter entrance increases are shown in Figure 5 and Figure 6.

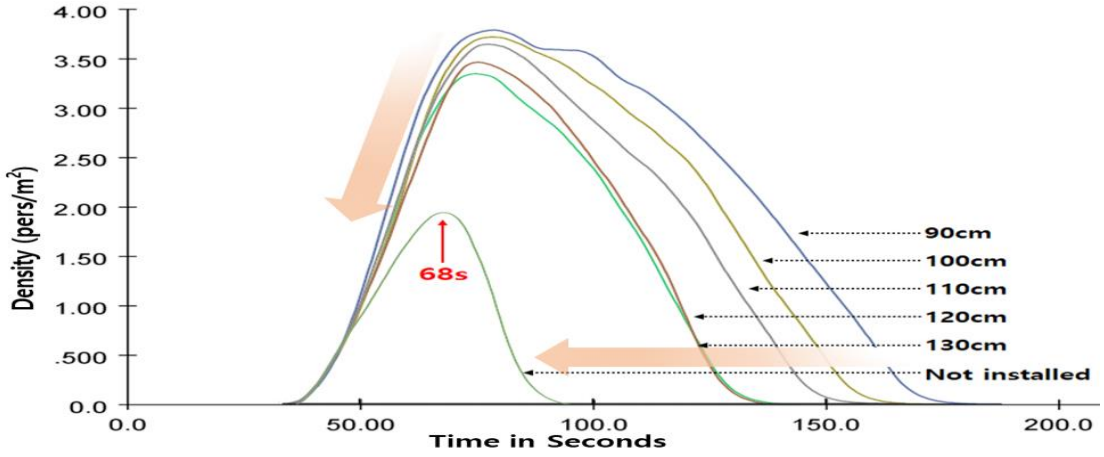


Figure 5. 3rd Floor central ramp entrance population density graph for scenario 2

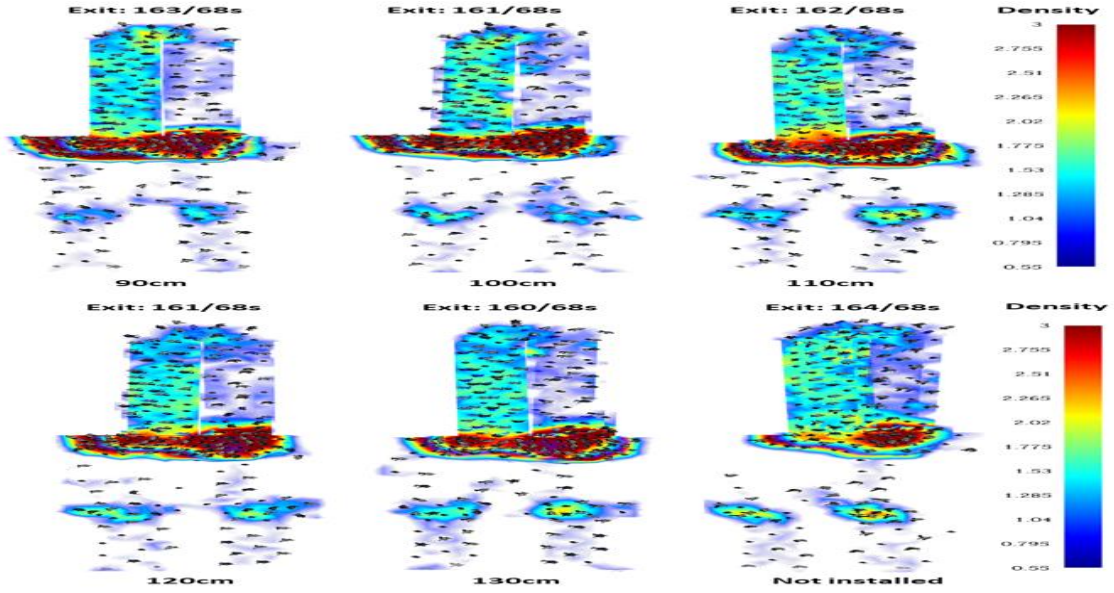


Figure 6. Scenario 2 - population density projection of the central ramp after 68 seconds of evacuation

Looking at Figure 5, as in the case of scenario 1, as the width of the entrance decreases, the population density tends to increase, and the evacuation time tends to increase. Looking at Figure 6, an average of 162 people completed evacuation at 68 seconds after evacuation started. The most severe bottleneck was when the entrance of the all-in-one shutter installed on the central ramp on the 3rd floor was 90cm. For this reason, the evacuation time was also measured as the longest at 228.5 seconds.

From the above results, it can be seen that the all-in-one shutter has the effect of preventing the spread of fire, but it can be an obstacle to evacuation and there is a difference in evacuation time depending on the width of the entrance. With the introduction of the 'Educational Facility Safety Certification System', safety management for educational facilities is being strengthened. It is a time when safety inspection standards for fire protection divisions considering evacuation safety and all-in-one shutters suitable for school sites are required.

4. CONCLUSION

In this study, based on the scenario in which the current state personnel arrangement and the personnel arrangement that takes the least evacuation time were set for a five-story high school building, this study investigated what changes in the evacuation time occurred when the all-in-one shutter installed along the fire compartment was activated. As the all-in-one shutter was installed, the bottleneck was severe and the evacuation time increased. When students evacuate by designating an evacuation exit with an all-in-one shutter with an entrance width of 100cm in the current staffing arrangement on the 2nd, 3rd, and 4th floors, the evacuation time is longer than when the all-in-one shutter was not installed. The evacuation time was measured to be longer than without installation even if the width of the all-in-one shutter entrance was expanded to 130 cm, which is half the size of the central road ramp. On the other hand, when students were placed on the 1st, 2nd, and 3rd floors under the same conditions, the evacuation time was almost the same as when the all-in-one shutter entrance was enlarged to 130cm. Although the all-in-one shutter has the effect of minimizing combustion and preventing the spread of fire in the case of a fire, it can be seen that it is an obstacle to evacuation activities. In order to secure evacuation safety in high-rise school buildings, first, as Lee et al. pointed out in the previous study, students need to be arranged from the bottom floor and an evacuation exit is designated to secure a safe evacuation time. In addition, it is necessary to check the safety of evacuation through fire and evacuation simulation driving in consideration of the location of the all-in-one shutter installed according to the fire division and the width of the all-in-one shutter entrance. According to the compliance criteria for automatic fire shutters and fire doors, it may be suitable for evacuation safety when the width of the entrance is expanded under the condition that the evacuation time required when the all-in-one shutter is not activated and the evacuation time when the all-in-one shutter is activated are the same. In order to verify this, additional research is needed on a method to secure suitable evacuation safety according to the width of the entrance installed in the all-in-one shutter. As a way to reduce the bottleneck caused by the all-in-one shutter, installing a sprinkler can be considered. If sprinkler facilities are installed in a school in accordance with Article 14(Standards for installation of fire compartments) (1) No. 1, all-in-one shutters can be installed within 3,000 square meters of floor area, not within 1,000 square meters of floor area. As the number of all-in-one shutters to be installed is reduced, the evacuation time can be shortened by that amount, which can help ensure evacuation safety. With the introduction of the 「Educational Facility Safety Certification System」, safety management of educational facilities is being strengthened to prevent student safety accidents. With the enactment of the 「Educational Facilities Act」, the legal basis for comprehensive and systematic management of all educational facilities was laid. In order to secure the safety of the entire educational facility, it is necessary to take urgent measures to improve the safety inspection standards for all-in-one shutters that

are an obstacle to the evacuation of students and to improve the fire compartments. Evacuation drills in the all-in-one shutter operation situation can help you safely evacuate without panicking in an actual situation. A previous study by Lim also emphasized the need for periodic education and training in preparation for the airport condition of students who are not familiar with the automatic fire door operating and closing when the entrance is closed. However, the lack of such evacuation drills in most school sites can be pointed out as an improvement in the safety inspection and management standards for educational facilities.

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