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Research Article

Analysis of the Difference in RSET According to the Change in the Height of the Stairs in the School

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Abstract: This study, in order to evaluate the safety of evacuation by comparing and analyzing the RSET according to the height change of the stair, which is a vertical evacuation route in case of fire in a high school building, Evacuation simulation was run the Pathfinder program changed the height change of the stair to 0.16m, 0.18m, and 0.2m for each male students and female students. In the case of female students, it was analyzed that when the final RSET height was 0.18m, 1.2 seconds were shorter than when 0.16m, and were the same as at 0.2m. Male students also found that when the final RSET height was 0.18m, 2.3 seconds were shorter than when 0.16m, and 0.5 seconds shorter than when 0.2m.

It was analyzed that even if the number of participants was increased and the evacuation simulation was executed, the safety of evacuation could be improved when the height change of the stair is 0.18m as the RSET when the height change of the stair is 0.2m is shorter than that of 0.16m and 0.18m.

Keywords: Stair, height change, pathfinder simulation, REST, evacuation safety

1. Introduction

1.1 Background and Purpose of Research

April 16, 2021 marks the 7th anniversary of the tragedy of the Sewol ferry destined for Jeju from Incheon to sink in the sea in front of Jindo, killing 299 people and missing 5 people. The Sewol ferry accident served as an opportunity to reinforce the need for disaster and safety accident prevention education at school sites in Korea, reflecting the necessity for such safety education at school sites for the next 7 years, and the Ministry of Education announced on November 11, 2014 in the field of education. Comprehensive safety measures were announced, and as a follow-up measure, life safety, traffic safety, violence and personal safety, drug and Internet addiction, disaster safety, occupational safety, and emergency measures were taken to improve school safety accidents on February 26, 2015.[1][2] The ‘Seven Standards for School Safety Education' of treatment were confirmed and announced.

In addition, according to the Ministry of Oceans and Fisheries, the government aims to raise a sense of safety in order not to repeat a disaster of human loss and to prepare thoroughly with a sense of great responsibility to protect the lives of the people. A complex facility related to marine safety called 'National Life Memory Center' is being built, and the 'Hull Main Zone and Treatment Project' is being promoted, and the National Maritime Safety Hall was built on the hillside near Paengmok Port in Jindo, which was used as a place to collect the remains of victims at the time of the disaster to raise public awareness of marine safety. This is in full swing.[3]

According to the analysis of major fires in the 2019 Fire Statistical Yearbook published in 2020 by the National Fire Data System of Korea's Fire Department, the number of major fires occurred in schools in 2019, with 45 cases (28.8%).[4][5] Then, 13 government offices (8.3%), 7 public buildings (4.5%), and so on.

Most of the existing school buildings are aged. Therefore, the durability and stability of existing school buildings gradually deteriorate along with electrical facilities, and the risk of fire is increasing. Property damage in the event of a sudden fire in an aging school building with a high risk of fire is also a problem, but the loss of lives of adolescents is a serious problem that can extend to social problems as seen in the Sewol ferry incident. Therefore, it can be said that the importance of evacuating quickly in case of an actual fire occurs.

In this study, evacuation simulation according to the height of the stairs that may occur in the route of evacuation using stairs among the vertical evacuation routes of buildings was performed, and the difference in RSET was analyzed to determine the level of installation regulations stipulated by the Building Act and Fire Fighting Act We will study the problems and suggest safe evacuation measures.

1.2 Scope and Methods of Research

The evacuation-related regulations in buildings cover a wide range of fire detection, initial fire extinguishing facilities, fire and fireproof structures, evacuation routes, and internal materials. Safety performance can be secured by simultaneously applying various countermeasures. However, if this is summarized, the scale or quantity is very large or large.[6]

Therefore, this study refers to the part of the Korean Fire Protection Act and the National Fire Protection Association(NFPA)'s 'Life Safety Code Handbook' that stipulates that stairs and ramps are designed as an evacuation route along with a corridor among evacuation facilities. The scope of the study was limited to those for stairs among the constituent elements of.

This study aims to compare and analyze the safety of evacuation by separating high school students by gender and analyzing the difference in the required safe egress time (RSET) through evacuation simulations with different heights of stairs. This is to make a proposal to systematically apply the facilities of a building for efficient evacuation along with a performance design.

1.3 Review of Prior Studies

Kim Young-soo and two others (2003)[7] calculated the appropriate dimensions of the stairs due to the difference in blood pressure and pulse rate according to the change in the height of the stairs in 'Study on the physical changes according to the height of the stairs when climbing stairs'. **Eun Seon-deok** et al. (2007)[8] analyzed the effect of the stair height on the walking pattern in the stair climbing activity of the elderly in 'A Study on the Physical Changes According to the Step Height Differences in the Elderly's Stair Climbing'. **Lee Seung-Hoon** and 3 others (2012)[9] compared the differences between men and women in the forward force and pronation moment of the knees of men and women in the stair-down motion in the 'Study on the kinematics of men and women when performing a stair-down motion'. **Kim Jun-dong (2017)[10]** analyzed that women are more influenced by lower limb muscle strength (psoas major, extensor thigh muscles) than men in 'Analysis of factors for increasing age that affect stair climbing and descending movements'. **Shinya et al. (2012)[11]** studied that the memory of the stair height increases when information about the stair height is obtained by walking up a shorter stair than when information about the stair height is obtained only visually. **Delin, Mattias** and 5 others (2017)[12] reported that while climbing long stairs of 48m and 109m in height, physical activity abilities such as walking speed, physical activity (oxygen consumption, heart rate and electromyography data), and perceived activity and behavioral changes over a long period of time. Since evacuation has an effect on walking speed, we tried to provide information such as fire safety design according to the height of stairs and correction of evacuation modeling tools. **Nu´bia R. da Conceic ˜o** and 6 others (2019)[13] analyzed the effect of Parkinson's disease (PD) on the perceptual judgment of stair height using both external sensory vision and receptive judgment.

Previous studies on stairs so far have calculated the appropriate dimensions of stairs due to the difference in blood pressure and pulse rate, the effect of the change in the height of the stairs on the gait pattern, strength analysis according to gender when climbing stairs, and the height of the stairs. The focus was mainly on the medical and kinematic perspectives, such as the ability to analyze information and the influence of intellectual judgment on Parkinson's disease. However, in the event of a disaster, studies on the safety of evacuation according to the shape of an important evacuation route such as the height of stairs are extremely rare or no.[14][15]

2. Theoretical consideration

2.1 Installation consideration

In Table 1, the effective width and landings of stairs in Korean high schools is 1.50m or more, the height of the stair is 0.18m or less, and the width of the stair is 0.26m or more. In addition, non-combustible materials must be used for both stairs and landings, whereas in the United States, the width of landings is 1.12m or more, the height of the stair is 0.178m or less, and the width of the stair is 0.279m or more.

Table. 1. Standards for Stairs Installation in Korea and U.S.

nation	Stairs and Landing Width	single height	Short Width	Application Criteria
Korea	1.50m min.	0.18m max.	0.26m min.	Rules on standards for evacuation, fire protection, etc. of buildings
USA	1.12m min.	0.178m max.	0.279m min.	NFPA 101(50 or more)

3. Performance Based Design by evacuation simulation

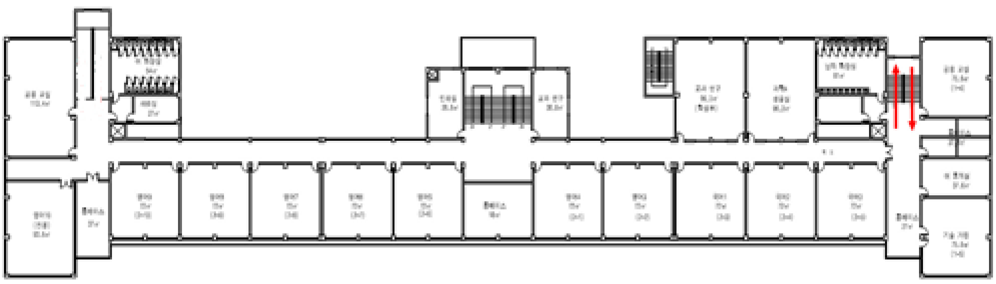
3.1 Evacuation model

The building subject to the evacuation test is the building of OO High School, and OOO is also located in OO City. This building is the main building of the school, co-education with 10 classes per grade, and has a total of 30 classrooms and 6 special rooms on the 1st, 2nd and 3rd floors. On the 4th floor, there are special classes and auditoriums. In Figure 1. (a), the final exit of the stairs installed on the right side of the first floor of the building is marked as Exit Door 02. In Figure 1. (b) and Figure 1. (c), the stairs are marked with arrows at the right end of the corridor for each floor.

Figure. 1. Floor plan of the main building of OO High School.

(c) 3rd floor plan

(b) 2nd floor plan



(a) Floor plan on the first floor

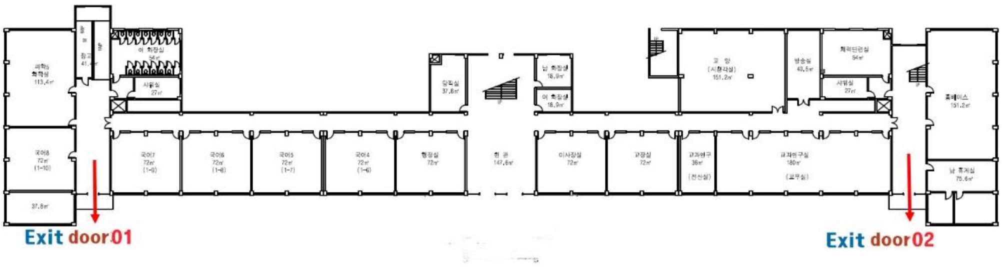


Figure. 2. is an actual photograph of the stairs of the target building, which was completed in 1983. The step height of this building's stairs is 0.18m, and it complies with the rules on standards for evacuation and fire protection of buildings.

Figure. 2. Stairs in the target building.

3.2 Scenario configuration

As shown in table 2, The composition of the scenario set the change in the height of the stairs to 0.16m, 0.18m, and 0.2m, respectively, setting the door02 on the first floor stairs for 25 male and female students, as the final refuge for the evacuation simulation.

Table. 2. Configuration of Scenarios.

Sortation	Stairs height(m)	Participants	Sex	Evacuation Final exit
Scenario 1	0.16	25	male / female	door 02
Scenario 2	0.18	25	male / female	door 02
Scenario 3	0.2	25	male / female	door 02

3.2.1 Scenario 1: When the height of the step is 0.16m

In the training of a virtual situation where a fire broke out on the 4th floor and expanded to the 3rd floor for 25 male and female students each, a simulation was performed on the evacuation in the direction of the stairs, which is the exit route on the right side of the building, passing through the corridor, which is a horizontal evacuation route. At this time, the height of all stairs was set to 0.16m, and door02, the evacuation exit on the first floor of the stairs side, was selected as the final evacuation exit of the evacuation simulation.

3.2.2 Scenario 2: If the height of the step is 0.18m

In the training of a virtual situation where a fire broke out on the 4th floor and expanded to the 3rd floor for 25 male and female students each, a simulation was performed on the evacuation in the direction of the stairs, which is the exit route on the right side of the building, passing through the corridor, which is a horizontal evacuation route. At this time, the height of all stairs was set to 0.18m, and door02, an evacuation exit on the first floor of the stairs, was selected as the final evacuation exit of the evacuation simulation.

3.2.3 Scenario 3: If the height of the step is 0.2m

For each 25 male and female students, in the training of a virtual situation where a fire broke out on the 4th floor and expanded to the 3rd floor, a simulation was performed on the evacuation in the direction of the stairs, which is the evacuation route on the right side of the building through the corridor, which is a horizontal evacuation route. At this time, the height of all stairs was set to 0.2m, and door02, an evacuation exit on the first floor of the stairs side, was selected as the final evacuation exit of the evacuation simulation.

3.3 Deferred evacuation time and possible evacuation time[16]

Evacuation delay time was used by the test formula "Estimation of evacuation start time" as shown in Expression (1).[17]

$$\text{evacuation initiation time (min)} = \sqrt{\sum A}/30 \quad \text{------- Expression (1)}$$

The maximum compartment area of A = 8.5, since the floor area of the classroom is 72m2. Therefore, evacuation initiation time (min) = 8.5/30 = 0.28 minutes, which translates into 17 seconds.

However, since the evacuation training was notified in advance in this study, the detection time and recognition time of the fire detector should be considered in the event of a fire do not occur. Therefore, the evacuation start time was set at 30 seconds, including the time of evacuation after listening to the broadcast in 17 seconds of Form (1) because it was assumed that the person in charge was directly evacuated through the broadcast. The evacuation time is set at less than four minutes as shown in Table 3.[18]

The minimum evacuation request time required for students to complete evacuation from a building is called Required Safe Egress Time (RSET), and the time when the fire reaches the hazard is called ASET (Available Safe Egress Time). According to Poon (2014), Wang, et al. (2015), achieving the goal of the disaster prevention design is judged to be the case where the RSET is below the ASET. And if the opposite is the case, it is judged that the evacuation safety performance of the target building has not been secured.[19][20]

Table. 3. Escape Time Criteria.

Building usage	**ASET** (available safe egress time)
office, commercial and industrial buildings, schools, universities(residents are familiar with the building's interior, alarms, escape rout es, and always awake)	4 minutes, or less

3.4 Input variables and input values

In this study, the input variables reflected in the Pathfinder evacuation simulation were divided into walking speed, evacuation initiation time, and shoulder width and applied as shown in Table 4.[21] Among the input variables, the shoulder width reflects the body size of 20 Korean body measurements based on the standard body type by gender and age.[22][23] Therefore, the shoulder width was based on 39.8 cm for boys and 35.7 cm for girls. The walking speed was calculated by applying 1.19 m/s to the average adult walking speed.[24]

Table. 4. Input variables and input values

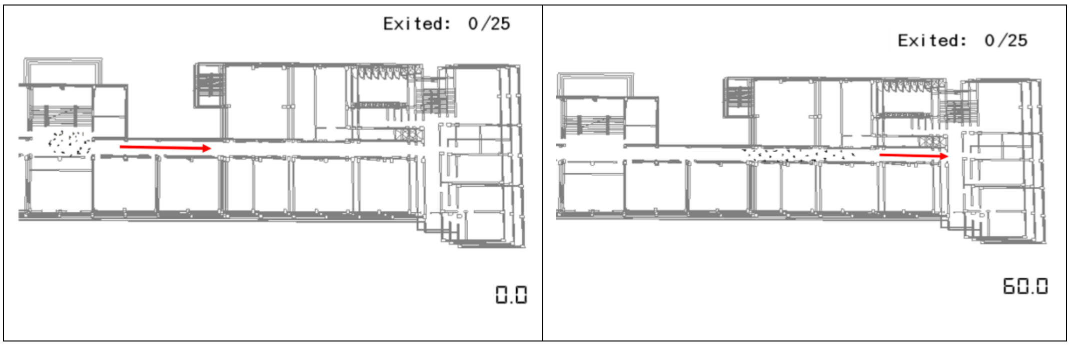
Input variable	Input values	Source
walking speed	man: 1.19 m/s woman: 1.10 m/s	The SFPE Handbook of Fire Protection Engineering 2
evacuation initiation time	30 seconds	Time for all occupants in the classroom to recognize training and begin evacuation
height	man: 173.4 cm woman: 161.2 cm	2019, Student Health Examination Sample Statistics
shoulder width	man: 39.8cm woman: 35.7cm	「Human Dimension Survey of Koreans(2015)」 Apply

4. Analysis of the difference in RSET according to the change in the height of the stairs

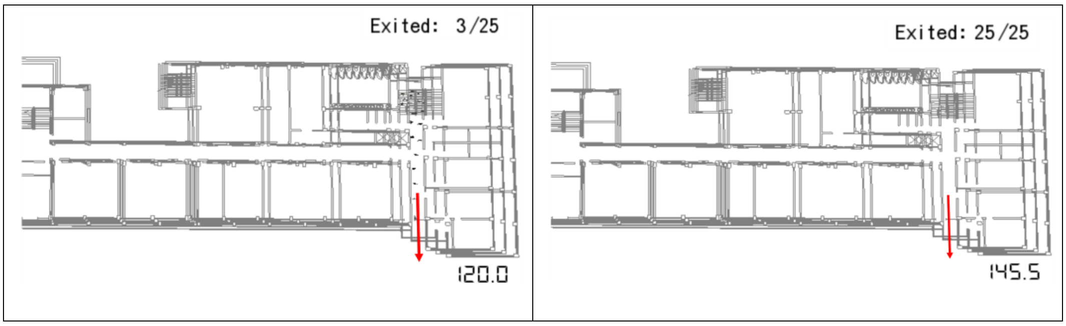
4.1 Scenario 1

Figure 3. shows the results of the evacuation simulation according to the time change of the female student's stairway evacuation route when the height of the stairs was 0.16m after the Simulated Fire Occurred. In the event of a fire, the female students start evacuating after 30 seconds, depending on the evacuation scenario. Various actions are performed according to the algorithm of the simulation, and the evacuation is completed after 145.5 seconds elapse from the start of evacuation.

Figure. 3. Hourly evacuation of female students when the height of the stairs is 0.16m.



(a) pre-escape (b) 60 seconds after evacuation



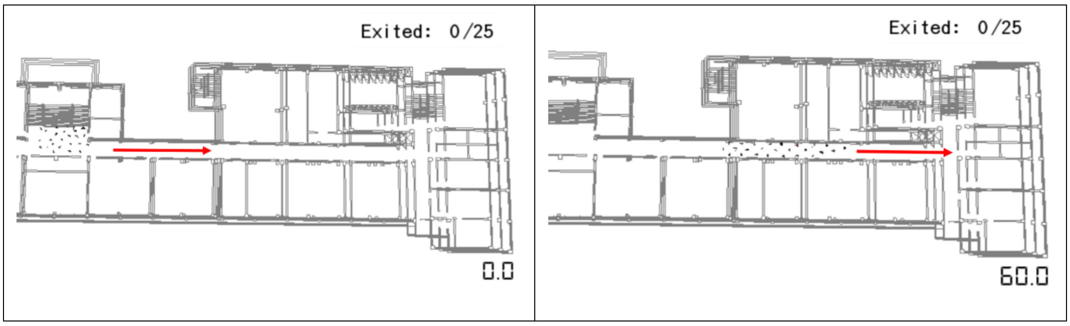
(c) 120 seconds after evacuation (d) Evacuation complete

In the case of male students, if a fire breaks out, evacuation starts after 30 seconds depending on the evacuation scenario. Evacuation was completed 137.6 seconds after evacuation was initiated, performing various actions according to the simulation algorithm. It was analyzed that RSET was shorter by 7.9 seconds compared to female students.

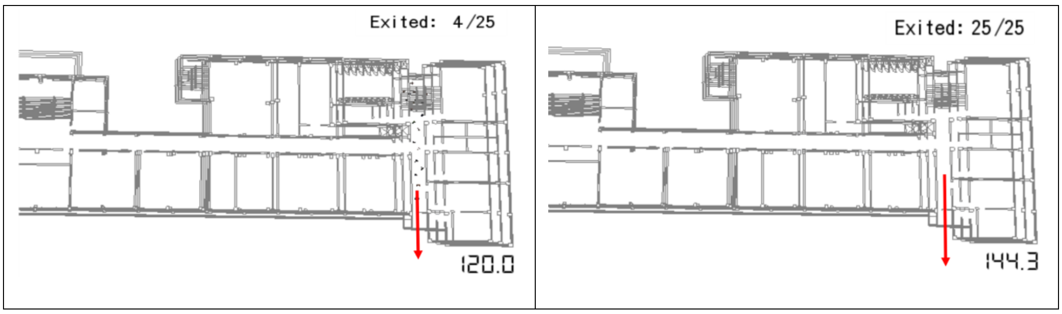
4.2 Scenario 2

Figure 4 shows the results of the simulation of a female student when the height of her hem was changed to 0.18m in Scenario 1. The evacuation was completed in 144.3 seconds after the start of evacuation, and 1.2 seconds were shortened compared to the 0.16m height. In the case of male students, evacuation was completed 135.3 seconds after the start of evacuation, and 2.3 seconds were shortened compared to 0.16m height. It was analyzed that the RSET was shorter by 9 seconds compared to that of female students.

Figure. 4. Hourly evacuation of female students when the height of the stairs is 0.18m.



(a) pre-escape (b) 60 seconds after evacuation



(c) 120 seconds after evacuation (d) Evacuation complete

In the case of male students, if a fire breaks out, they will begin evacuation after 30 seconds depending on the evacuation scenario. Following the simulation's algorithm, the evacuation was completed after 137.6 seconds of evacuation. It was analyzed that RSET was reduced by 7.9 seconds compared to girls.

4.3 Scenario 3

Figure 5 shows the results of the simulation of a female student when the height of the step is changed to 0.2m in Scenario 1. Evacuation was completed in 144.3 seconds after the start of evacuation, and 1.2 seconds were shorter than when the height of the step was 0.16m, but the time required for evacuation was the same as when the height of the step was 0.18m. In the case of male students, evacuation was completed in 135.8 seconds after the start of the evacuation, which was 1.8 seconds shorter than when the step height was 0.16m, and 0.5 seconds increased from when the step height was 0.18m. RSET was analyzed to be shorter by 8.6 seconds compared to female students.

Figure. 5. Hourly evacuation of female students when the height of the stairs is 0.2m.

(a) pre-escape (b) 60 seconds after evacuation

(c) 120 seconds after evacuation (d) Evacuation complete

As a result of the simulation, in all scenarios, the evacuation time of male students was shorter than that of female students, and this result is analyzed because male students' walking speed is faster than female students.

The RSET values of the simulation results according to the height of the stairs are shown in Table 5. In the case of female students, it was analyzed that the final RSET was the same when the stair height was 0.18m and 0.2m, which was 1.1 seconds shorter than when the tier height was 0.16m, so there was no significant difference. It was analyzed that male students' final RSET was shortened by 2.3 seconds compared to 0.16 m when the stair height was 0.18 m, and 0.5 seconds shorter than when the final RSET was 0.2 m, so there was no significant difference from female students.

The maximum distance of evacuation for female students was 100.3m when the height of the stairs was 0.18m, which was 102.8m and 2.5m shorter than the maximum distance of 0.16m and 0.2m, but the distance did not appear to have affected RSET. The results of the simulation of male students also showed the same tendency as female students. In addition, the simulation results of the change in the height of the stairs set by 25 people in Table 5 showed that both the final RSET and the average RSET were fast at 0.18m, but the difference between 0.18m and 0.2m was not significant for both boys and girls.

Table. 5. Simulation results with single-height changes.

Sortation	Stair Height(m)	Min. RSET(s)	Final RSET(s)	Avg. RSET(s)	Travel Distances Max.(m)
female	0.16	113.3	145.5	132.5	102.8
	0.18	112.2	144.3	130.9	100.3
	0.20	113.4	144.3	131.2	102.8
male	0.16	107.5	137.6	125.3	103.9
	0.18	106.6	135.3	123.2	102.4
	0.20	107.6	135.8	123.6	101.2

To improve the reliability of the simulation results, we set the number of participants in the simulation to 50 and show the results of our analysis in Table 6. It was analyzed that there was a slight difference between the number of male and female students when the number of male and female students was 50. Although there is no significant difference in the height of the stairs, both men and women, the final RSET and the average RSET tend to reduce slightly from 0.16m and 0.18m. The data also showed that both final and average RSET were reduced at 0.18m or 0.2m from 0.16m in height of stairs for both boys and girls. In the case of female students, 3.4 seconds shorter than 0.16m when the final RSET was 0.2m in height of stairs, and 2.1 seconds shorter than 0.18m.

Male students also analyzed that the final RSET was 2.8 seconds shorter than when the height of stairs was 0.2m compared to 0.16m and 0.7 seconds shorter than when the height of stairs was 0.18m.

The maximum evacuation distance for girls was 108.5m, which is 0.5m shorter than 109m at 0.16m, but 1.3m longer than 107.2m at 0.18m, which does not appear to affect RSET, as did the result of 25 participants. The male student simulation result also showed the same trend as that of female students.

Table. 6. Simulation results with single-height changes.

Sortation	Stair Height(m)	Min. RSET(s)	Final RSET(s)	Avg. RSET(s)	Travel Distances Max.(m)
female	0.16	113.3	166.9	144.2	109.0
	0.18	112.2	165.6	143.7	107.2
	0.20	113.7	163.5	142.0	108.5
male	0.16	107.3	158.4	137.0	108.3
	0.18	106.9	156.3	135.2	107.4
	0.20	107.7	155.6	134.9	107.6

5. Conclusion

In this study, in order to evaluate the safety of evacuation by comparing and analyzing the RSET according to the change in the height of stairs, which is a vertical evacuation route in case of fire in a high school building, the Pathfinder program sets the heights of stairs to 0.16m, 0.18m, and 0.2m for each male and female. An evacuation simulation was run while different.

The results of the study are as follows.

(1) In the case of female students, it was analyzed that the final RSET was the same when the height of stairs was 0.18m and 0.2m, which was 1.2 seconds shorter than when height of stairs was 0.16m, so there was no significant difference.

(2) For male students, the height of the stairs is 2.3 seconds shorter than 0.16 m when the final RSET is 0.18 m and 0.5 seconds shorter than 0.2 m, making little difference from female students.

(3) The maximum travel distance for female students to evacuate was 100.3m when the height of stairs was 0.18m, which was 102.8m and 2.5m, the maximum travel distances of 0.16m and 0.2m, but the movement distance does not seem to have affected RSET. The results of the male student's simulation also showed the same trend as that of the female student.

(4) Evacuation simulations show that both male students and female students had shorter RSET at 0.18m or 0.2m than 0.16m, with a maximum travel distance of 100.3m to 102.8m for female students and 101.2 m to 103.9m for male students, but shorter RSETs for male students with faster walking speeds.

(5) When running the evacuation simulation by increasing the number of participants, RSET at 0.18m and 0.2m in the height of stairs did not differ significantly, but the reduction of 3.4 seconds in female students and 2.8 seconds in male students compared to 0.16m in the height of stairs increased evacuation safety.

As a limitation of this study, there is a regret that it was not possible to prove the difference in RSET when the height of the stairs is 0.18m and 0.2m by evacuation experiment by installing an actual building. As a future research project, it is necessary to increase the reliability of evacuation safety through simulations and experiments according to the slope of the ramp and the height of the stairs. In addition, it is necessary to further increase the number of participants or conduct a case of 0.22m in height to study evacuation obstacles such as bottlenecks.

In conclusion, in the evacuation simulation according to the change in the height of the stairs, it was found that the safety of evacuation was relatively secured when the height of the stairs was 0.18m or 0.2m, with no significant difference in gender and number of people. Therefore, the implication of this study is that it is necessary to determine the height of stairs through evacuation safety evaluation for each use of specific fire targets, and the regulation of the height of stairs uniformly applied irrespective of the use of specific fire targets.

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