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A Study on Securing Safety for High Rise Building Fires - Applying Active Fire Escape Systems -

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Abstract Under the Korean Enforcement Decree of the Building Act, all high story apartment houses more than 5 stories high are mandated to install a fire evacuation system to ensure safe evacuation from fire accidents and providing quick and easy bi-directional escape route when main entrance is blocked by flame or toxic smoke. However, the current fire evacuation system shows a lack of understanding from residents and thus is widely ignored for having insufficient safety functions, especially vis-à-vis fire emergencies. Studies have found that an alternative evacuation method, the escapable fire evacuation system, has been analyzed for safety evaluation compared with the conventional passive fire escape system and can bring efficient and safer solutions, providing high rise residents escape from fire accidents. Evaluation for safety evacuation has been performed by the Fire Dynamics Simulation and applying Pathfinder simulation. This resulted in providing appropriate escape routes within the safety escape time and allowed for people in high rise building fires to get to safety.

Keywords Escape type evacuation system, Evacuation awareness, High-rise building fire, Fire escape simulation, Required safety evacuation time

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1. Introduction

1.1 The purpose of the study

This study has investigated the characteristics and problems of the evacuation system applied for fire evacuation of residential high-rise buildings with high fire frequency. In addition, this study intended to suggest an effective evacuation method by encouraging the active evacuation of residents when a fire occurs through an evacuation effectiveness review for an evacuation system through which people can immediately escape to the outside of the building.

1.2 Study methods and procedures

Based on the survey contents, the main factors for securing the safety of high-rise fire evacuation through the residents' perception of the fire evacuation system and failure cases of evacuations are examined, and the types and characteristics of the evacuation system are classified. Based on this survey, the form with the optimal evacuation efficiency is derived and the evacuation effectiveness of the escape type evacuation system is analyzed based on the evacuation simulation.

1.3 The background of the study

The rapid industrialization of Korea since the 1970s and 1980s has led to the densification of the urban population. The number of high-rise residential buildings has exploded, and the residential environment has changed rapidly to high-rise apartment buildings. As a result of these changes, as of 2016, the number of apartments exceeded 10 million for the first time, and the composition of apartments in the total housing accounted for 60.1%. (1).

The number of fires in high-rise residential buildings is also increasing along with the increase in the number of residents in high-rise apartment buildings. Consequently, casualties and property damage are also increasing. The Korean government introduced the National Fire Information System, established in 2007, in order to analyze the situation, collect information statistics related to fires, and use them as data for fire prevention. As a result of analyzing the frequency of fire issuance in the last 10 years in the 2019 Fire Statistical Yearbook published by the Fire Department, the average number of fires over the past 10 years was 42,652, with 2,176 casualties, and 443,137 million won (about 397 million USD) in property damage. (2) Urbanization in Korea is progressing very rapidly, centering on densely populated Seoul, metropolitan areas, and local metropolitan

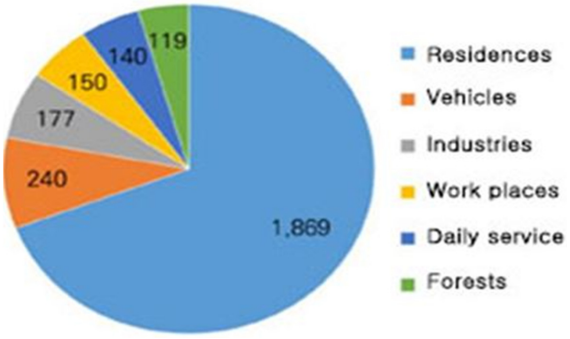


Figure 1. Analysis of fire occurrence report over the last 10 years, 'Fire Statistical Yearbook 2019', published by Korea National Fire Agency (Fire Statistics yearbook, 2019)

areas. It can be seen that fire damage in high-rise residential apartments is increasing significantly. (3)

According to Jin (2018)'s fire risk rating of buildings by the Society of Fire Protection Engineers (SFPE) and evaluation of fire frequency, casualty, and property damage by facility use, apartment houses was found to have the highest fire risk rating, rather than high-rise buildings for other purposes in terms of fire risk. (4)

On the other hand, most of the rescuers show that it is faster and safer to use the elevator rather than the direct stairs to evacuate a high-rise building in the event of a fire in a high-rise residential building (Hui, 2019) (5). However, when the evacuation elevator cannot be operated due to a fire in a high-rise building, there is a high possibility that it may cause large-scale casualties.

The purpose of this study was to analyze the problems of the in-door type evacuation system based on the public's perception of the evacuation safety and evacuation usefulness of fire evacuation facilities that must be installed in high-rise apartments in Korea. In this study, reviewed and tested for necessity of escape type of evacuation system which is an efficient evacuation system and could make a direct escape to the outside of the high-rise building for adequate evacuation while searching for alternative to fire evacuation at the same time. It also proposed safe and expeditious evacuation measures from fires in high-rise residential buildings. Based on the box-type external evacuation system, the study applied CFD simulation which is a method for evacuation safety evaluation to drive the evacuation safety results. In particular, the evacuation efficiency (awareness, speed, safety) of escape type of evacuation system through the outside of the building was reviewed by analyzing the fire situation that could occur in a high-rise residential building from the various perspectives.

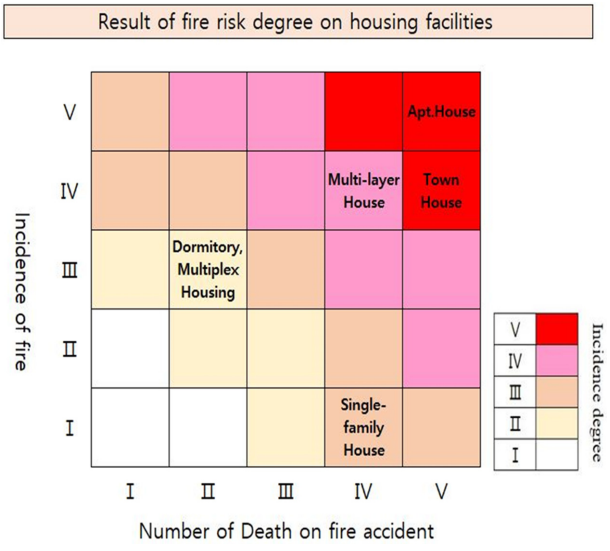


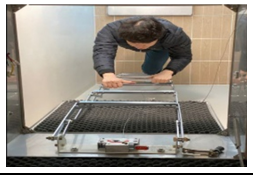
Figure 2. Table of fire risk degree on housing facilities.

2. Preliminary Considerations

2.1 Review of evacuation system

The living environment has rapidly changed from apartment buildings to skyscrapers in Korea by urbanization and industrialization. Economic development and improvement in income level considering the increase in the number of single-person households, increase in the proportion of time spent indoors due to the impact of COVID-19 and changes in the living environment, the internal housing structure is expected to gradually change in various ways. However, while the convenience of living in a residential space is rapidly being pursued, the progressiveness of fire evacuation facilities inside high-rise residential buildings is being developed slowly. In Korea, in order to prepare for the risk of fire due to the trend of apartment houses centered on high-rise residential buildings and the increase in the use of combustible materials by the Enforcement of the Building Act from 1992, it is mandatory to install fire escape facilities in new residential apartments with 5 or more floors. As shown in Table 1, these fire evacuation facilities include lightweight partitions for evacuation and

Table 1. Types of passive indoor fire evacuation facilities

Type of Facility	Image
Indoor Evacuation Space	
Light-weight Partition	
Top-down Evacuation Ladder System	

rescue inside the building, evacuation spaces on balconies, and descending ladders through indoor top-down evacuation exits.

A characteristic of such fire evacuation facilities in buildings are difficult for residents to evacuate to the outside of the building when a fire occurs and the external escape toward the entrance is blocked with flames and toxic gases. The common characteristics of these evacuation systems are not selected for performance and safety reasons, but are installed for economic reasons and maximization for the residential space. However, evacuation failures due to high-rise fires have repeatedly occurred due to a lack of awareness as an evacuation facility through the survey of general residents, and the limits of passive evacuation performance facilities stipulated by the current building law enforcement ordinance are not deviated. Recently, products have been developed that allow active, immediate evacuation from flames and toxic gases to the outside of the building rather than the inside of the building, allowing rapid escape from the danger range of a fire source to the ground floor, in order to overcome these shortcomings of evacuation facilities in buildings. The products include an external descending ladder, a handrail-type evacuation stair, an elevator-type evacuation device, and a folding externally deployable product are representative all of have the common feature of being installed outside the building

2.2 The classification of evacuation systems

In high-rise residential buildings, a completed evacuation means that all occupants reach the safe ground floor outside the building without any casualties due to the characteristics of the high-rise apartment building and the residential characteristics of a large number of people living together. From the point of view of this definition of evacuation can be divided into ① the residence type that stays inside the building and passively waits for rescue, and ② the active type that allows the occupants to escape to the outside of the building themselves. A residence-type evacuation facility where residents stay for evacuation facilities in the definition of Article 2 of Apartment Evacuation Facility Performance set by the Ministry of Land. According to these classification criteria, lightweight partitions, evacuation spaces, and indoor top-down evacuation exits are installed inside the building, the residents stay in a specific space passively wait for rescue, or after temporary evacuation within a limited range to neighboring households inside the building, it was classified as a stay-type evacuation system in that external evacuation was accomplished with additional assistance.

The recently introduced external descending ladders, handrail-type evacuation stairs, elevator-type evacuation devices, and box-type externally deployable facilities are installed outside the building. Residents can use them to evacuate themselves without external assistance, such as rescue, and this is classified as an active evacuation system.

2.3 Evacuation awareness

When an evacuation route is blocked by flames due to a fire, an effective safe evacuation system is important to provide an alternative evacuation route and to make the residents aware of fire and ultimately lead to evacuation behavior. It is important for an effective and safe evacuation system to provide an evacuation route in another direction as an alternative when the door, which is an evacuation route, is blocked by flames due to a fire. This allows the residents to recognize it as an evacuation action. However, the stay-type evacuation system did not meet the prompt evacuation demand due to the psychological evacuation resistance due to the decrease in evacuation confidence following a limited range of evacuation and waiting for rescue in fear of fire while staying indoors both appearing as lack of awareness of evacuation facilities. As a result of analyzing the data of Kim (2019) in Table 2, which investigates the general public's perception of the residence-type evacuation system (6), 75.8% of the respondents answered that they did not know how to escape or that it was impossible to escape when a fire occurred. It can be seen that the residence-type evacuation system lacks awareness and efficiency in terms of evacuation facilities

Table 2. Awareness of existing passive indoor fire evacuation system (Hurley, 2016)

Content	Survey Result	Rate	Notes
Reliability of Passive Evacuation System	Dependable	24.1%	Unreliable and unconcern for Evacuation System : 75.8%
	Useless	42.1%	
	No concern	33.7%	
Awareness of Passive Evacuation System	Light-weight Partition	32.8%	Showing no concern for any of fire evacuation system : 36.5%
	Indoor Evacuation Space	13.2%	
	Other	12.8%	
	Top-down Evacuation Ladder	4.7%	
	No concern	36.5%	
Improve Awareness of Passive Evacuation System	Yes	72.7%	Demand for improvement of fire evacuation system : 72.7%
	No need	20%	
	No concern	7.3%	
Reason of Improvement	Difficulty	32.8%	Necessity of improvement: 70.6%
	Dangerous	8.3%	
	Deterioration	29.5%	
	Other	22.8%	
	No concern	6.6%	



Figure 3. Study case showing fire evacuation failure. Press release by Ministry of Public administration and Security, May 23, 2019.

when a fire occurs. In another survey, when asked if they knew whether there is a fire evacuation facility, 59.2% answered "Yes"', which was 18.4%p higher than that of 'No' (40.8%) (7). As a result of the survey on how to use the balcony fire evacuation facility, the highest response was 'use it as a warehouse' with 41.1%. the second was 'leave it empty' with 28.9%, 'don't know' came in third place with 19.5%, and 'there was no evacuation facility due to structural change' came in fourth place with 10.5%. That means only 28.9% are likely to function as a fire evacuation facility, the remaining 71.1% have lost their function as an evacuation facility, and are not recognized. This lack of awareness of residence-type evacuation facilities leads to a loss of function of evacuation facilities when a fire occurs in high-rise residential buildings and then leads to casualties.

Therefore, it is necessary to change the perception of fire evacuation facilities in high-rise residential buildings that can actually be used to improve the system to increase awareness.

2.4 Evacuation safety

In general, risk perception in fire evacuation revisited (2015) data (8), which analyzes patterns of evacuation behavior in case of a fire. It can be seen that each step takes time in the decision making process of fire recognition, risk recognition, evacuation decision, and evacuation action. According to the joint investigation by the Ministry of Public Administration and Security, the Ministry of Land, Infrastructure and Transport, the Fire Service, and the National Disaster and Safety Research Institute reported on May 23, 2019, the victim's behavioral patterns were recognized, reaction, and evacuation were analyzed in three steps. ① In the recognition step, it was difficult for the victims to secure an evacuation time because their awareness of the fire was delayed due to sleeping at night. ② In the reaction step, victims were not aware of the existing evacuation system and reacted toward the bright light outside that eventually led to death by falling from the window. ③ In the evacuation step, there are repeated cases of victims failing to evacuate because they

Table 3. Summary of in-door passive fire evacuation facilities and its features

Type of Facility	Features (Evacuation cognition rate based on Kim(2019)	Example of cognition failure and misuse of evacuation facility
Indoor Evacuation Space	- Evacuation cognition rate: 13.2% - Temporary dwelling space for fire rescue while it is unable to escape from fire toward outside. - High-rise residents are unable to escape from fire.	
Light-weight Partition	- Evacuation cognition rate: 32.8% - Easy to install with low cost. - Light-weight partitions are normally blocked by living stuffs while it is difficult to break the partition.	
Top-down Evacuation Ladder System	- Evacuation cognition rate: 4.7% - Builders prefer to install for low cost and space-saving reason despite of privacy problem. - Inconvenient to escape for elder person and children.	

cannot secure another evacuation route when the entrance is blocked. A typical failure case of an evacuation facility is a light-weight partition that induces evacuation to an adjacent household, as shown in the Figure in Table 1, to evacuate when the partition between the households is destroyed using a tool such as a hammer. However, in certain situations such as a weak evacuation, it is impossible to escape after destroying the wall of the light-weight partition alone. Also if the adjacent household is blocked by the storage of household items and storage, it is impossible to evacuate and the function of the evacuation facility is lost.

The evacuation space is a facility that secures a space of 2§³ or more in the balcony space to avoid fire and stays for at least 60 minutes. As a result of an actual fire test, it was found that the temperature inside the evacuation space exceeded 100 degrees Celsius 20 minutes after the occurrence of the fire, and increased to 200 degrees Celsius after 60 minutes, resulting in loss of the function as an evacuation shelter. (A study on the influence of temperature in evacuation space by fire door heat transfer (2013) (9)). On the other hand, Liu et al. (2018) showed that the indoor top-down evacuation exit has the advantage of shortening the time required for evacuation in that it is possible to evacuate to the lower floors, unlike light-weight partitions and evacuation spaces (10) However, children and elderly have difficulty operating and evacuating and also many residents complain about noise between the upper and lower floors and the possibility of the invasion of privacy. In addition, in the top-down evacuation exit, there is a risk of a second accident such as a fall during the evacuation process. This is because a problem occurs in the process of evacuating in a vertical direction after the folding ladder installed inside is unfolded. In fact, on July 26, 2015, a 12-year-old child fell downstairs and died through a top-down evacuation installed in the evacuation area of an apartment on the 35th floor in Haeundae-gu, Busan in Korea (11).

2.5 Evacuation validity

After Kim (2019) reviewed the perception of the residence-type evacuation system based on a survey of the general public and the case of evacuation failure, the main elements of a high-rise fire evacuation system are: ① Awareness of evacuation, ② Safety of evacuation, and ③ speed of evacuation. Among the factors to consider for evacuation, the cognitive failure of evacuation cannot guarantee the safety and speed of evacuation. In other words, the lack of awareness of the stay-type evacuation system, was examined through the previous failure cases, should enable the residents to evacuate safely and quickly in an urgent fire situation but as shown in Table 3, in the case of the indoor top-down evacuation area surveyed by Kim (2019), the recognition rate of evacuation facilities is only 4.7% because it is structurally installed on the wall or located on the floor of the residential space misused as a warehouse or locked. The lack of awareness of evacuation reduces the effectiveness of evacuation in case of emergency in preparation for another evacuation route, even though it is a facility in case the main entrance is blocked by fire. Therefore, as a major factor to consider in high-rise fire evacuation, it is necessary to institutionalize the various evacuation systems so that regulations can be improved to increase the awareness of the evacuation system in normal times and to ensure rapid and safe evacuation in the event of a fire.

2.6 The necessity of evacuation system improvements

As the floor plan of high-rise buildings is gradually becoming more complex and diversified, as a result of comprehensively examining the effectiveness of evacuation based on evacuation failure cases and perception surveys of it, the stay-type evacuation system is a major factor to consider in high-rise fire evacuations. It can be seen that there is a limit to securing the awareness of evacuation facilities safety and the speed of evacuation needs to be improved.

3. Escape type evacuation system review

3.1 The importance of two-way evacuation

In the 2019 Fire Statistical Yearbook, the number of fires by ignition point (total of 26,023) was the highest in 9,344 cases (36.3%) in living spaces, 4,949 cases (52.4%) in the kitchen and 1,281 cases (13.6%) in the bedroom. As shown in the statistics, fire ignition occurs most frequently in living spaces, such as kitchen fires 52.4% and bedroom fires 13.6%. In terms of fire evacuation,



Figure 4. Fire accident on March 12, 2009 (ⓒimnews. imbc.co.kr)



Figure 5. Image showing failure of fire evacuation route blocked by household stuffs. (light-weight partition was installed)

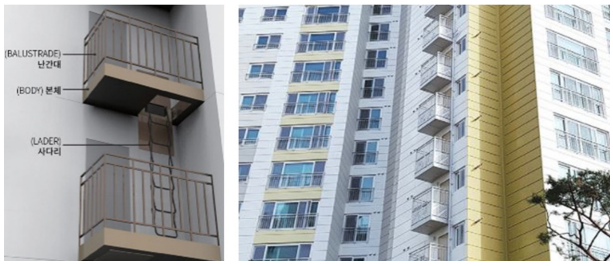


Figure 6. An image of top-down evacuation ladder system. (ⓒ www.019ddd.com)



Figure 7. Foldable external evacuation stairs (ⓒwww.finednc.com)



Figure 8. Top-down elevation system (ⓒwww.nearigo.com)

death caused by suffocation rapidly spreading flames and toxic gases, and secondary casualties such as fall deaths occurring during evacuation because the main entrance is blocked and additional evacuation routes are not secured due to smoke that obstructs visibility (12).

Professor Kobayashi of the Department of Fire and Disaster Prevention at the Tokyo University of Science and Technology, Japan, emphasized the improvement of the fire resistance performance following the tragic disaster at the Grenfell Tower in London on June 14, 2017. In addition, not only the main evacuation route is secured but an additional evacuation route through a balcony should be secured. (13). It is important to additionally provide an evacuation route through which people can escape outside in both (2) directions when the entrance is blocked by fire because recently new high-rise residential buildings tend to expand “balconies” from the beginning of construction. However, in case of a fire in a high-rise residential building, these evacuation systems with lightweight partitions, evacuation spaces, and indoor top-down evacuation exits do not provide an immediate evacuation route to the outside. Thus the casualties continue.

The absence of a two-way evacuation facility is not only in Korea but also in most developed countries. In addition, in developing countries the supply of high-rise residential buildings is rapidly increasing in recent years in Southeast Asia, such as China, Vietnam, and Indonesia. Here, it is easy to find cases in which the evacuation path is blocked due to the failure to provide a safe exit route. (Hao, Jiahong, Min, Yun, 2019) (14). Therefore, in a newly constructed high-rise residential building should be prepared for efficient evacuation by installing a fire evacuation facility inside the building as an alternative way of evacuation.

3.2 Types of escape type of evacuation systems

Currently, there are four types of escape evacuation systems installed outside high-rise residential buildings. ① It is a descending ladder product with an integrated protruding escape exit. This product provides an active evacuation route to the outside in case of fire. However, the evacuation method takes the form of a descending ladder the same as indoors, there may be restrictions in evacuation for the vulnerable due to the swaying of the ladder. In addition, as it is installed in a protruding form on the outer wall in the direction of the rear of the building, it usually impairs the aesthetics of the building, so there is a feeling of rejection in actual application.

② It is also possible to use handrail-type evacuation stair products that use a balcony to escape to the outside. This product normally functions as a safety handrail, but it is opened to the evacuation stairs with a simple operation of an escapee in case of a fire. The feature of the handrail-type is that it is installed on the windows and doors of the balcony exterior wall, so, the evacuation awareness is good in case of a fire, and active evacuation is possible im-mediately to the outside of the building.

However, residents are completely exposed to external heights in the process of escaping from a high floor, evacuation fatigue may occur due to fear of heights. This product is installed on the front or rear windows (more than 2 m length) of the building, also it may interfere with the outside view and design of the facade.

③ This is an elevator type evacuation device installed



Figure 9. External deploy fire evacuation system. (ⓒ www.arero.co.kr)

inside and outside the building. It is convenient for vertical direction evacuation using an elevator, and most cases of single evacuation escape quickly. It occupies a certain amount of space due to the mechanical structure, and is limited by the installation location for the space efficiency.

④ There is a box-type externally deployable fixed ladder product that is installed in the form of a louver in air conditioner out-door unit rooms, which are highly utilized in high-rise residential buildings.

The characteristic of the externally deployed fixed ladder product is that it is normally installed in a louver type on the window frame in contact with the outside of the building on the balcony. Therefore, there is no obstacle to the elevation of the building or design. And in case of fire, it is deployed horizontally and vertically to enable evacuation by simple operation. The box-type external deployment fixed ladder product unfolds in the form of an evacuation box and cage structure, so it is possible to quickly escape from a high-rise building in a stable state without fear. This active evacuation system is highly recognizable as an evacuation facility in normal times, and it provides another evacuation route other than the entrance to enable active fire escape of residents, enabling evacuation in two (2) directions.

Currently installed in high-rise residential building active evacuation systems are summarized at Table 4 below summarizes the characteristics of the active evacuation system.

3.3 Feature of escape type evacuation system

A common feature of escape-type evacuation systems is that in case of fire, when the main entrance blocked with flames and smoke, it provides another evacuation path in the opposite direction to recognize ① the recognition of fire ② reaction ③ and shortening the decision-making time for evacuation. This is so that residents can actively and immediately evacuate to the outside of the building. In particular, with the exception of the elevator-type evacuation system, it is installed outside adjacent to the kitchen, living room window, and utility room that are closely related to the living space of the residents. Therefore, easy visual recognition makes for a quick evacuation. However, if the evacuation takes place outside the building, it may increase the risk of falling from a high-rise building during the evacuation and bottleneck can occur due to anxiety and fear caused by exposure to heights. In addition, various advantages of active evacuation can be utilized by resolving the damage to the exterior view or design caused by the external installation of the evacuation facility for the purpose of property value and the pursuit of the building elevation design.

Above all, it is necessary to improve the outdoor escape type evacuation system with the following so that the vulnerable (such as the young and old) can evacuate easily and safely:

1) Is it possible for the vulnerable to evacuate, such as the young, old, and the disabled?

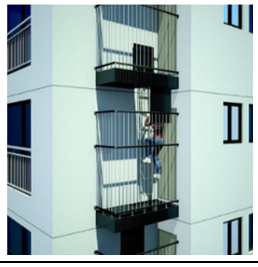
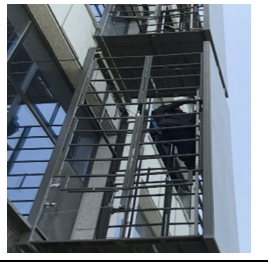
2) Is it possible to prevent secondary damage from fear of heights and falls?

3) Is it possible to immediately evacuate to the ground regardless of the number of floors?

4) Is there any damage to the design of the exterior facade of the building?

5) Is it easy to install and economical?

Table 4. Summary of escape type evacuation systems and its features

Type of Facility	Top-down ladder system	Foldable evacuation stairs	Top-down elevation System	Foldable External deploy evacuation system
Image of fire evacuation				
Features	- Provide active escape route toward out-doors. - Rescues are exposed to fresh air in fire. - Inconvenient escape with top-down ladder. - Low-cost installation and easy maintenance. - Installation is limited to rear side of building due to disturbance of facade design.	- Providing intuitive and simple escape route. - Fast escape from fire flame and smoke during evacuation. - Rescues are exposed to heights causing acrophobia. - Installation is limited to sliding windows. - Degrading facade design of building.	- Fast escape from fire with descending elevation system. - Escape route limited to certain space due to mechanical structure. - High cost and difficult to install. - Requires periodic maintenance. - Installation limited to multi-purpose building.	- Providing direct and active escape route. - Stable and convenient escape regardless of height of building. - Rescues are unexposed to heights providing easy escape. - No restriction on building design with foldable system. - Low cost with easy installation.

With these considerations, an evacuation effectiveness was analyzed through simulations based on CFD (Computational Fluid Dynamics) which is evacuation awareness based on the evacuation flow of the escape type evacuation system, high-rise evacuation operability from a structural point of view.

3.4 Awareness of escape type evacuation system

As shown in Table 3 at the actual site, the lack of awareness of the normal evacuation system of the stay-type system is left unattended in a state where evacuation is difficult or impossible in case of emergency. On the other hand, the escape type evacuation system, as shown in the Figure (6, 7, 9 and Table 4) is installed in a protruding from outside the building due to the nature of the installation according to the operation structure of the product, (1) allowing the residents to be repeatedly visually exposed, (2) indoor space utilization and privacy protection is good, (3) installation and the evacuation awareness is good compared to the stay-type evacuation system in the same way as the publicity and explanation of the operation method. In particular, if the escape-type evacuation system is installed outside the building, it is highly likely that the unconscious recognition of symbolism and visual repeated exposure as an evacuation facility leads to evacuation behavior that will utilize the evacuation system immediately leading to rapid evacuation in case of emergency. It is important for residents to quickly recognize an evacuation facility as an evacuation system, but stay-type facility clogged with household items that makes it difficult to recognize it as an evacuation facility. Regarding this, Lim (2017) proposes setting standards for signs or providing an evacuation guide so that people can recognize that it is an evacuation space in order to secure the effectiveness of evacuation of a stay-type evacuation facility (15). In the case of the escape-type system, as a result of this study, most of the escape-type systems provide evacuation guidance as shown in Figure 10 so residents can clearly recognize that it is an evacuation system in normal times and alarm sounds when operating due to fire. By adopting this alarm function, neighbors or residents can immediately recognize the occurrence of a fire.

4. Evacuation Safety of Escape Type Evacuation System

4.1 Review of Evacuation route

The evacuation flow after evacuation recognition of an escape type facility outside the building assuming a fire in a high-rise residential building is compared and analyzed as Table 5. The ignition point for the review of the evacuation route was assumed to be a kitchen and bedroom fire with high fire frequency. In case of the elevator-type device, it is installed at the end of the corridor instead of inside apartment that leads directly to the outer wall of a high-rise commercial building, so it was not included in the analysis of the movement.

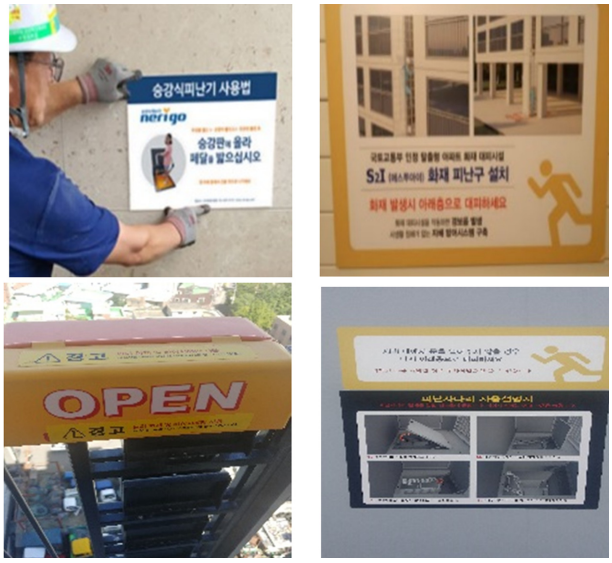


Figure 10. Various sign notice ensuring installation and awareness of escapable evacuation system.

The characteristic of the evacuation flow provided by the escape type evacuation system is that it helps in quick decision-making from the recognition stage to the evacuation stage in case of fire. ① The external descending ladder type installed at the back of the building allows for a quick escape from a kitchen fire, but for a bedroom or living room fire, an intuitive evacuation route is somewhat lacking due to the installation location. ② The evacuation stair railing type is the most effective in terms of evacuation flow and visual when the evacuation location is the living room or bedroom window.

However, it is a separate matter for the design to be infringed by being attached to the railing of the window. ③ The box-type external fixed ladder provides an escape route to the outdoors through a utility room at the balcony, which is frequently used within the household, so there is no fear of blocking the evacuation flow, also it is possible to provide a new evacuation route while the problem of design infringement of the building has been resolved.

4.2 Review of performance and efficiency review according to evacuation method

Another fact that needs to be considered is that due to the rapid spread of flames and smoke, all occupants of the building, including those on the fire-occurring floor, must reach the ground floor safe within the allowable time and complete evacuation. In order to review the high-rise evacuation performance, we first focus on the external descending ladder type that is installed frequently among evacuation systems, and the elevator type evacuation system, which is considered to have the fastest evacuation time. Based on the evacuation method the evacuation time of all occupants, assuming a fire, was compared through

Table 5. Evacuation routes of active fire evacuation system

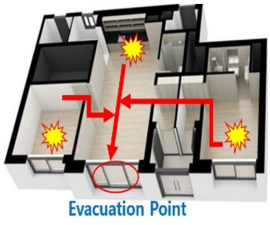
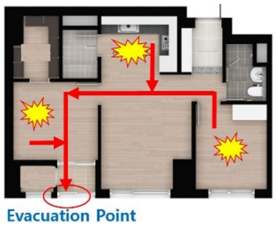
Evacuation Point and features	Evacuation Route
Top-down ladder system: External wall of building near to kitchen. Mostly efficient to escape from kitchen fire while evacuation route rather far from bed room fire.	
Foldable evacuation stairs: Living room window. Multi-directional evacuation access from both kitchen and bed room fire.	
Foldable External deploy evacuation system: Utility room. Versatile access for utilizing living flat structure from both kitchen and bed room fire.	

Table 6. Escape time measurement(s) based on height of 3.2meters. (National Fire Agency, 2019)

Per Person	M-1	M-2	M-3	M-4	W-1	W-2	W-3
Type 1	13.0 sec.	11.4 sec.	11.2 sec.	12.0 sec.	16.5 sec.	16.0 sec.	14.4 sec.
Type 2	8.6 sec.	6.2 sec.	6.6 sec.	6.0 sec.	9.4 sec.	7.2 sec.	7.8 sec.

Note: Type 1: Top-down ladder system, Type 2: Top-down elevation system

Tables 6 and 7. As a result of analyzing the evacuation time based on the CFD-based Pathfinder simulation of the external descending ladder type, the detailed results for all 120 occupants to evacuate from the 21st floor to the ground floor are different for each simulation case. However, it showed a very quick result of evacuation completion in from min 226 seconds to max 435 seconds. (Liu, Kim, Lee, 2018, 10-2)

However, this is a measurement of the result of the vertical evacuation speed of the simulation, and because of the structure of the descending ladder that reaches about 3 meters, the evacuation delay and mistakes caused by the evacuation operation and use of the residents due to the ladder swinging as shown in Figure 10 (a) are not considered. Therefore, it is difficult to say that evacuation can be achieved at such a high speed only with the result of the evacuation speed of the simulation. Actually, it was

Table 7. Evacuation Apparatus Subject to Fire Evacuation Capability (Choi, 2014)

Classification	Escape Transport Capability by Organization (sec/person)			
Type of Location	Type 1		Type 2	
	3F(9 m)	5F(15 m)	3F(9 m)	5F(15 m)
Nursing Homes	X	X	15	25
Infants and Toddlers	X	X	15	25
Property for Sale	120	200	15	25
Low-rise Accommodations	120	200	15	25
Low-rise Public Housing	120	200	15	25

※ ① X :Not available ② Adult(76 kg), Children(20 kg)

found that the evacuation time of the descending ladder through a field test that considered various characteristics of pedestrians took 11 to 16 seconds for one floor with a height of 3.2 meters and 200 seconds for a height of 15 meters with 5 floors above the ground. (Choi, Na, 2014) (15)

For the handrail-type evacuation stairs installed on the windows, living room or bedroom balcony, the evacuation stairs are deployed and fire evacuation is made through them. Figure 11(b) In the process of vertical evacuation, residents are exposed to high altitudes, so there is a possibility of secondary accidents due to fear of heights.

Therefore, in analyzing the effectiveness of evacuation through simulation assuming that it is difficult to get a meaningful result because all residents in a building are evacuated to the ground floor from a high-rise building fire, evacuation difficulties, delays and effectiveness are excluded but only simulation setting factors such as walking speed, shoulder width, and height according to the age of residents are included. The evacuation bottleneck caused by evacuation hesitation due to psychological anxiety as a result of exposure to the height of the stairs is not included. As shown in Figure 12, the box-type externally



Figure 11. Actual use of the top-down ladder system on the left and the foldable evacuation stairs on the right.



Figure 12. Fire drill image of the external deployed evacuation system. A front panel installed to avoid acrophobia with stable ladder fixed front. (ⓒwww.arero.co.kr)

deployable fixed ladder using the multipurpose room as an external evacuation a box-shaped horizontally deployed makes downward evacuation possible. In addition, a fixed ladder is arranged in the front for easy vertical evacuation, enabling stable evacuation without secondary accidents such as falls due to the sway of the ladder as seen in the external descending ladder type. In addition, when operating on the fire floor, all floors are automatically deployed, it connects the route using a fixed ladder which runs directly from the hazardous space to the ground.

It is important for evacuation facilities of high-rise residential buildings to be able to quickly evacuate to the ground floor without fear from exposure to heights from the point of view of rescuers in case of fire.

4.3 Evacuation System Review

In order to evaluate the safety of escape type evacuation systems, it was important to ascertain whether the residents could safely complete the evacuation to the ground. However, as mentioned above, although it has advantages in terms of safety and speed of evacuation from high floors, it is difficult to generalize the effectiveness of high-rise evacuation through the elevator type evacuation machine, which is difficult to provide in various places from fire sources due to the structure of the facility, so it was excluded from the evaluation. In addition, from the residents' point of view, attempted to block exposure to heights and to exclude bottlenecks that could occur during the evacuation process based on a fixed ladder. In addition, based on the simulation study result (10-1), evacuation using ladders is faster than stairs, the box-type externally deployable fixed ladder products were chosen as the evaluation target for escape-type CFD simulation. The results were derived by applying the safety evaluation method. The evacuation route of the box-type externally was set to reach the ground floor using the fixed ladder installed in the front after entering in the multi-purpose room assuming a bedroom fire and kitchen fire. It was collectively assumed as the characteristic of the elderly with the slowest speed.

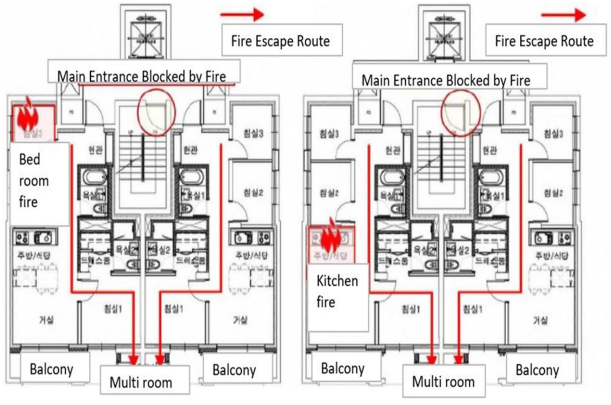


Figure 13. Establishing fire escape route using external deploy evacuation system.

4.4 Simulation Review

The high-rise evacuation safety evaluation of the system is based on a CFD simulation, after measuring the Allowed Safety Evacuation Time (ASET), and comparing them with each other, "Evacuation Allowed Time (ASET) > Evacuation Required Time (RSET, Required Safety Evacuation Time)" condition must be established before it can be judged that evacuation safety is secured. Evacuation Allowable Time (ASET) measures the time it takes for residents inside a space to reach a dangerous limit due to combustion products such as deterioration temperature, smoke, and carbon dioxide. Allowable time was measured, and the evacuation required time (RSET) was measured using a Pathfinder evacuation simulation. In the FDS simulation setting, a hydrodynamic model was applied to numerically analyze the flow of smoke and heat transfer caused by a fire accident and the radiative heat transfer was analyzed in a similar way to the finite volume method through the Radiation Transport Model, which is a radiative transfer method for non-dispersive gray gas. The combustion model assumed that the mixture reaction between fuel or combustibles and oxygen proceeded infinitely fast.

Evacuation Allowable Time (ASET) evaluation criteria evaluates the toxic effects centered on smoke breathing line, heat exposure effects, line-of-sight effects, and carbon monoxide, and analyzes the time for occupants in the space to reach danger due to fire. The evaluation of ASET > RSET (Required Safety Evacuation Time) were established so that the required evacuation time was established. The evacuation time evaluation criterion was set as the time required for residents to complete evacuation from the fire to a safe space and the time required to complete evacuation activities enter the escape-type evacuation system is the completion point of the evacuation.

4.5 Validation of escape type evacuation system

4.5.1 Evacuation Scenario Setting

The input condition of the simulation of the evacuation system are as a result of collecting statistics on the number of floors of apartment complexes across the country for the last 3 years from the building statistics provided by the building life history management system of the

Table 8. Calculation of Occupancy Numbers

Floor	Place of Fire	Floor Area	Co-Efficient	Capacity
Floor 1	Bed room & Kitchen	145.6 m^2	18.6 m^2 /person	8 persons
Floor 2~15		92.6 m^2/ Unit	18.6 m^2 /person	10 persons /floor

Ministry of Land, Infrastructure and Transport. Apartments in the size section accounted for 33.7% of the total apartment building, so 15 floors were selected as the most popular apartment floors, and the exclusive area of 59 m^2 was determined through the LH standard housing floor plan derived from the Korea Land and Housing Research Institute in consideration of the domestic apartment size and various supply methods. It was attempted to secure the standard of the evaluation target by establishing a standard floor plan. (17).

Assuming 10 people per floor, 148 residents in total, all residents were set as the physical characteristics of the elderly over 60 who are most vulnerable to fire (walking speed, male 0.7 m/s, female 0.97 m/s). For the fire scenario, the evacuation effectiveness was the worst case suitable for the Fire Department, the fire location was assumed to be the bedroom and kitchen fires with the highest fire risk.

The evacuation scenario is based on the performance-oriented method of firefighting facilities and applied standard basis attached Table 1 announced by the Fire Department, when the 4th floor of the ignition fire occurred in the evacuation route with the internal doors opened. Applying with Polyurethane Foam-GM (General Material) 23 (SFPE) by Handbook of Fire Protection Engineering, Fifth Edition, Table A. 38-39) (18), the smoke generation rate was 0.227 g/g, and the evacuation time allowed for residents by combustion products such as visibility and CO concentration was measured. The maximum heat release rate of the fire case in bed room was applied 1,000 kW (18) and 5,131 kW for a kitchen according to the performance-oriented design method and standards for firefighting facilities. An initial temperature of 20 degrees Celsius, a simulation time of 1,200 seconds, and the total number of grids were set to 2,020,000. The evacuation simulation was set for the first evacuation completion point to complete entry into the escape-type evacuation system, and the second evacuation completion point to reach the ground floor. The time required for vertical evacuation activities until the following was included in the evacuation time of residents.

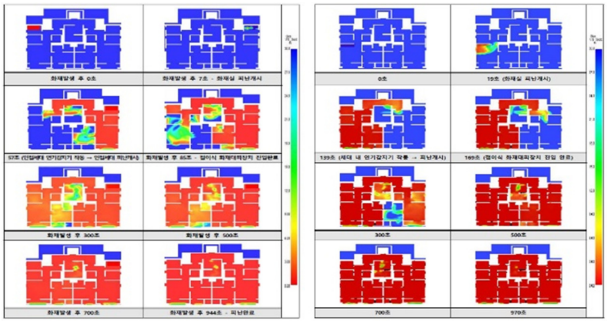
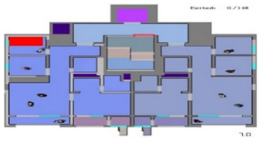
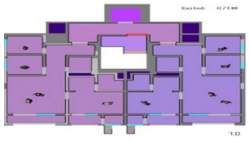
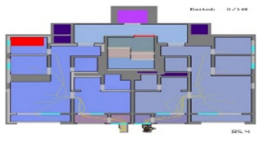
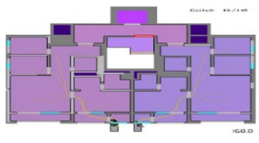


Figure 14. Image of smoke spreading over the fire event.

4.5.2 Simulation performance

In the evacuation safety evaluation based on the bedroom and kitchen, the visibility measurement point for each floor first reached the standard for the safety of people, but within the evacuation allowable time, all occupants of a total of 148 people entered the outdoor active evacuation system installed on each floor was completed. Due to the smoke spreading from the 4th floor above the ground, the existing evacuation route was contaminated in 38 seconds for bedroom fires and 102 seconds for kitchen fires after a fire. Subsequently, it lost the function of an evacuation route. However, occupants on the ignition floor performed vertical evacuation activities through the fire evacuation device in 168 seconds for bedroom fires and 180 seconds for kitchen fires after the fire occurred through the additional evacuation route formed by the installation of an outdoor active evacuation system. As a result, in the case of a bedroom fire, a total of 944 seconds (15 minutes 44 seconds) and a kitchen fire in a total of 958 seconds (15 minutes 58 seconds), all occupants in the building completed the evacuation to the outside the building. Through this, even when the direct stairway, which is a single evacuation route, is contaminated, all residents of the building use the outdoor active evacuation system so that no evacuation failure occurred, and the evacuation time required for the residents is less than the evacuation allowable time. Thus the evacuation effectiveness of the outdoor active evacuation system was sufficiently secured.

Table 9. Evacuation simulation progress of fire and non-fire floor

	
Fire ignition floor (4th floor) Evacuation starts after 7 sec. from fire	Other floor(15th floor) where evacuation starts from 7 sec.
	
Evacuation completed after 85 sec. (safely entered into evacuation system)	Evacuation completed after 168 sec. (safely entered into evacuation system)

4.5.3 Effectiveness Evaluation

Based on the previous escape-type evacuation system, two evacuation safety evaluation scenarios conclusions were drawn as a result of multilateral analysis of the effectiveness of evacuation in fire situations that may occur in high-rise apartment buildings.

(1) When conducting an evacuation safety evaluation, the direct staircase is the only evacuation route which was contaminated and the blocked. It makes it impossible to evacuate to the outside of the building.

But a clear two-way evacuation route was secured after the outdoor evacuation system was installed as an additional evacuation route staircase.

(2) All residents completed the first evacuation with the evacuation system within the evacuation time per floor even when all the entrances to the living room were open. The second vertical evacuation to the ground was safely completed using the escape-type evacuation system which secured the evacuation effectiveness of the escape-type.

(3) By applying the notification of the Fire Department, "performance-oriented design methods and standards for fire-fighting facilities, etc.", to set the scenario of severe conditions that can occur in apartment buildings, after evacuation started in the absence of a fire compartment by a fire door on the route the residents entered the escape-type evacuation system safely in minimum 25 seconds to maximum 113 seconds on each floor without any fire damage.

(4) It was confirmed that the function as a fire evacuation device for providing an evacuation route in both directions of the building works effectively as all residents completed evacuation to the ground outside the building. The times for each scenario were 945 seconds bedrooms (15 minutes 45 seconds) and 958 seconds (15 minutes 58 seconds) kitchen fire.

(5) The escape-type evacuation system serves to expand the options for evacuation routes compared to the stay-type evacuation system, also the function as a high-rise evacuation facility can be sufficiently performed in terms of evacuation stability and effectiveness.

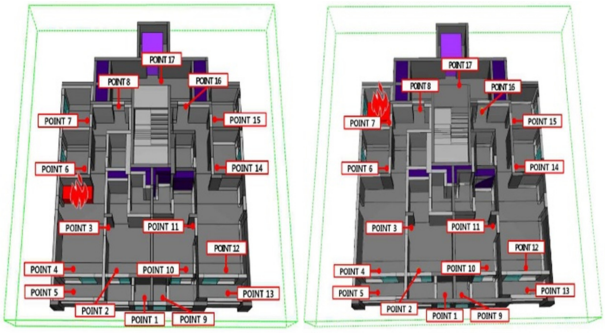


Figure 15. Diagram of fire check point of bed room fire and kitchen fire.

Table 10. Evacuation safety results of fire ignited floor

Check Point	FDS Simulation	Pathfinder	Safety Result
	ASET	RSET	
P 1	101 sec.	41 sec.	Secured
P 2	53 sec.	24 sec.	Secured
P 3	34 sec.	20 sec.	Secured
P 4	30 sec.	11 sec.	Secured
P 5	38 sec.	10 sec.	Secured
P 6	22 sec.	10 sec.	Secured
P 7	10 sec.	9 sec.	Secured
P 8	17 sec.	Not used	Secured
P 9	644 sec.	87 sec.	Secured
P 10	179 sec.	73 sec.	Secured
P 11	98 sec.	68 sec.	Secured
P 12	82 sec.	61 sec.	Secured
P 13	109 sec.	60 sec.	Secured
P 14	59 sec.	59 sec.	Secured
P 15	59 sec.	59 sec.	Secured

4.6 Evaluation consideration

The evacuation effectiveness of the escape-type evacuation system was evaluated using the high-level blocking and fixed ladder of the externally deployable evacuation system to shorten the evacuation time based on the evacuation psychology of evacuees in a situation such as an actual high-rise fire with the stability of high-rise evacuation in mind.

Evacuation effectiveness was analyzed according to the evacuation characteristics of evacuees, and the resulting evacuation safety was analyzed based on FDS (Fire Dynamics Simulation) and CFD simulation centered on Pathfinder. As a result of the safety evaluation based on the evacuation simulation, evacuees in the event of a high-rise fire are quickly aware of evacuation when using the active evacuation system, as a result, they can escape quickly. Thus, the effectiveness of evacuation has been secured. As a result of this study, the evacuation method through the active evacuation system that can evacuate to the outside of the building is more efficient than using the direct stairs and stay-type evacuation system in case of high-rise residential buildings. And the evacuation time is shortened and the evacuation safety is improved.

5. Conclusion

This study performed an examination of the evacuation awareness, safety, and effectiveness of the evacuation system, including which factors to consider for evacuation as a fire preparedness measure according to various environmental changes in Korean housing. The characteristics and evacuation performance of the active evacuation system were investigated as an alternative to evacuation failure

due to the lack of awareness of the stay-type evacuation system. As apartment housing gradually become taller, evacuation safety and the speed of fires are lost due to the lack of evacuation awareness in residence-type facilities use of the stairs directly through the front door in high-rise residential buildings. Fire casualties are occurring repeatedly. Recent high-rise apartment buildings, there is a balcony that acts as a buffer for evacuation in both directions in case of fire because balcony extensions have become legalized. This study focused on kitchen and bedroom fires, where fires frequently occur, to examines the evacuation flow of an active evacuation system capable of escaping in both (2) directions to the outside of the building. The safety and effectiveness of evacuation simulations were evaluated from the evacuee's perspective by examining the performance and efficiency of each product according to the evacuation method and optimizing the safety and speed of evacuation, which are major factors to consider in high-rise evacuation.

As a result, in the event of high-rise building fire, when residents are exposed to high altitude, active evacuation is induced to the outside of the building, and high-rise building residents can quickly and safely evacuate without failure. In order to quickly evacuate from a fire in a high-rise residential building and to increase the evacuation effect of the active evacuation system, this study proposes the application of a box-type active evacuation system that can be installed in an exterior of the buildings. If the application of the active evacuation system is expanded through improvement, it is considered to secure an evacuation route in both (2) directions in an emergency situation and increase the evacuation effectiveness and also, it is possible to reduce human damage through safer and faster evacuation from high-rise residential building fires. Finally, it is necessary to create an environment in terms of the legal system to raise awareness of evacuation according to various changes in the built environment to introduce various types of escape-type evacuation systems that enable safe and rapid evacuation.

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