Turkish Journal of Computer and Mathematics Education Vol.12 No.13 (2021), 5975-5982

Research Article

Analysis of Time Spent to Carry Out Age-Based Simultaneous and Sequential Simulated Fire Evacuation in Indoor Gymnasium

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Abstract:
The study aims to analyze time spent to carry out age-based simultaneous and sequential simulated fire evacuation in indoor gymnasium. The result shows: First, it took 334.8 seconds to carry out simultaneous evacuation for RSET of all occupants, which demonstrated bottleneck phenomenon in the steps along the aisle of audience seats and entrance of fire door. Second, it turned out that it took a total of 352 seconds to carry out sequential evacuation which set the 1st priority on children followed by the elderly and grown-ups in the space of 10 seconds. Third, it was revealed that it took a total of 325.1 seconds to carry out sequential evacuation setting 1st priority on children followed by the elderly and grown-ups in the space of 20 seconds. Finally, when the interval was set at 30 seconds, it took a total of 313.6 seconds to complete sequential evacuation with the other conditions being made identical to the above one. The result shows that fire evacuation setting 1st priority on occupants slow to move and time interval at 30 seconds is the most effective in saving evacuation time.

Keywords: Indoor gymnasium, evacuation time, simultaneous evacuation, sequental evacuation, detection time

1. **Introduction**

As the urban areas are increasingly filled with buildings due to further complicated urban environment and growing population, the speed is also picking up to build taller buildings for more efficient land use which otherwise might end up with failure to meet growing demand for land.[1] If fire breaks out inside a building, indoor temperature will grow to trigger airstack effect which causes smoke to move upwards and induces fire to spread into the entire building with greater consequences to taller buildings. [2]

In the event of fire outbreak, it would be desirable to use stairs as the evacuation path leading evacuees to get out of the affected building.[3] If fire grows out of control, however, stack effect could inhibit evacuees from using stairs with exit being no longer available. If that happens, evacuees has no other choice but to rely on evacuation instrument for urgent evacuation. The simulated evacuation program shows that evacuees are unlikely to move towards the nearest and familiar exit and use safety exits despite growing risk of heat and smoke. What's more, the problem is that evacuation safety assessment may involve comparison of tolerable evacuation time and required evacuation time at a certain point based on developer's experience and knowledge level in order to change the result of evacuation safety level.[4]

The study, supposed that fire breaks out in a gymnasium, aims to classify spectators based on age and analyze evacuation time during which children, the elderly and the young walk towards stairs and are evacuated out of the affected building under the simulated evacuation program.

Kim Jin-Ho(2009)[5] sorted through regulations regarding evacuation facilities to suggest ways of upgrading operation of indoor gymnasium and architectural conditions and focused on identifying fire evacuation distance and time by involving evacuation simulation program. Cho JOng-Dae(2002)[6] used computer simulation program to develop ways of ensuring performance of fire protection system by demonstrating virtual smoke diffusion and fire behavior so that fire safety may be guaranteed according to a variety of Dome-shaped stadium-specific fire protection regulations.

Cho Seong-Jin(2014)[7] used simulation program to demonstrate massive scale of evacuation process in

professional sports stadium so that a large number of occupants may be under efficient control by upgrading their safety awareness. Kim Gwang-Hyeon(2011)[8] applied performance-based design to indoor stadium buildings so that the occupants' evacuation safety may be assessed by quantifying evacuation completion time(RSET) and evacuation threshold time(ASET).

As with research on evacuation, Kim Jin-Ho(2009) and Cho Jong-Dae(2002) focused on developing ways of ensuring performance of fire protection facilities based on research regarding evacuation distance and time in the event of fire outbreak to indoor gymnasium and smoke diffusion and fire behavior of Dome-shaped stadium. Cho Seong-Jin(2014) and Kim Gwang-Hyeon(2011) delved into evacuation safety assessment of the occupants based on efficient management and performance-based design by upgrading safety awareness of the occupants.

The conventional studies focused on identifying evacuation time and distance varying according to fire types and developing ways of ensuring fire protection facilities. In addition, they centered on efficient control of a large number of evacuees and securing performance-based building design for assessment of evacuation safety. On the other hand, this study, supposed that fire breaks out to indoor gymnasium, focused on analyzing evacuation time based on age in order to minimize human injuries and fatalities.

In order to ensure safe and quick evacuation in the event of fire outbreak to indoor gymnasium, it is necessary to secure fire protection design so that evacuees may swiftly move to stairs and exits featuring evacuation facility. To this end, the study involves evacuation simulation program to minimize fire-induced damage and develop evacuation measures by gauging evacuation time varying according to occupants' age under simulated fire program.

2. Evacuation Simulation

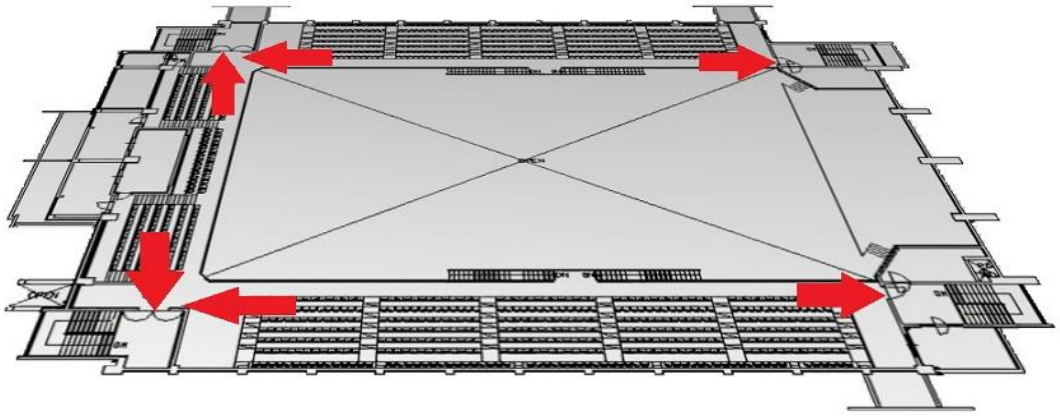
2.1 Simulation composition

Evacuation simulation program(Pathfinder) allows detailed bodily features such as height, shoulder width and walking speed to be input and essentially performs 3D simulation as well as visualization of fire and smoke behavior. It may be linked to fire simulation program called Pyrosim and may perform evacuation simulation during the linkage, successfully demonstrating virtual evacuation.[9] Pathfinder Program serves to describe human behavior based on computer, collect data and demonstrate individual behavior pattern based on SFPE handbok. Furthermore, it may vividly describe evacuee's behavior in the form of occupants' density, geography, deviation from existing route, change in movement speed following collision among evacuees, backward steps or outpacing and others.[10]

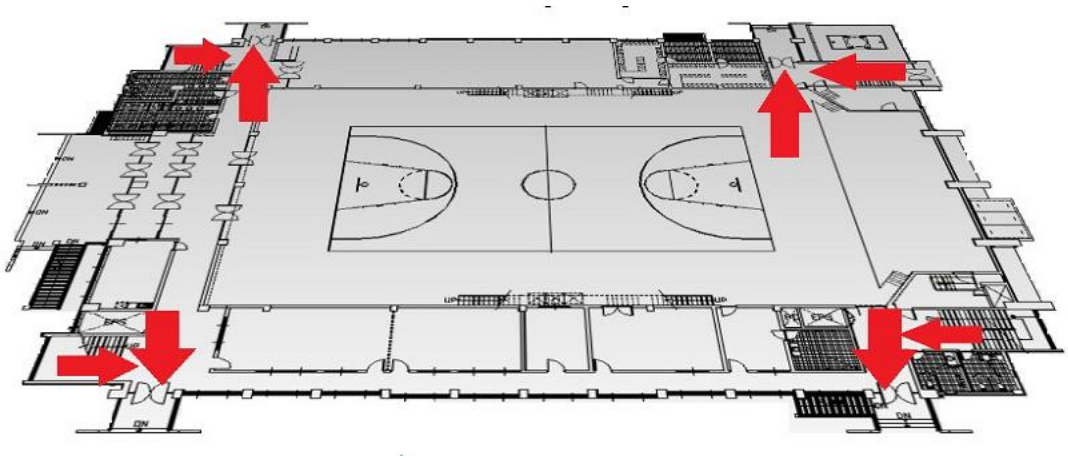
2.2 Architectural outline of affected building

The affected building is an indoor gymnasium building whose registration license was acquired in Aug. 2004 incorporating sports facilities encompassing basketball, baseball and fitness rooms. The building occupies area of 2,657.82 ㎡, comprising one basement and two floors with the building-to-land ratio reaching 14.92 % and total floor area 3,028.71 ㎡. Basement 1 comprises electricity and machine rooms, occupying area of 326.67 ㎡. The 1st floor occupies area of 2,373 ㎡, comprising indoor gymnasium, fitness and office rooms, while the 2nd floor occupies area of 1,021.26 ㎡ comprising stand, projection room and lighting room. The 2nd floor is connected to stair area comprising four fire doors in front of the stand, being connected to the 1st floor comprising exits. The stairs bridging 2nd floor to 1st floor incorporate stair lamps, and 1st floor is designed to incorporate evacuation lamps leading up to exits. The structure features stage in the front entrance of 1st floor, mobile basketball facility in the middle, and the 2nd floor features the stand with about 1,000 ㄷ-shaped seats so that spectators may enjoy the unfolding sports game. Fig. 1 shows evacuation path on the 1st and 2nd floor building design so that the evacuees may get out of the building from 2nd floor.

Figure 1. Guide map showing evacuation path on the 1st and 2nd floor of indoor gymnasium



a) 2nd-floor plane plan



b) 1st-floow plane plan

2.3 Assignment of personnel

The personnel assigned to 1st floor of the gymnasium include manager, fitness instructor, other sedentary workers and cleaners. When simulated evacuation program is activated, the number of people affected on the 1st floor and 2nd floor is 50 and 1003 respectively, including workers and fitness personnel on the 1st floor and 1000 occupants in the stand and 3 personnel assigned to operation of lighting room on the 2nd floor based on criteria for calculating the number of occupants as shown in Table 1. In the event of fire outbreak, about 1,000 occupants will be evacuated by walking down four fire doors and stairs from 2nd floor and get out of the building by using four exits built in the evacuation area on the 1st floor. The evacuation time would slightly differ among the children, the elderly and grown-ups.

Table 1. criteria for calculating number of occupants[11]

Usage	m^2/person
Fitness room	4.6

2.4 Input variable of occupants

The occupants comprise the children, grown-ups and the elderly. The children are males and females aged between 8 and 13, whose height and shoulder width are summarized on average. The grown-ups are aged between 30 and 50, whose height and shoulder width are summarized on average. The elderly are aged between 60 and 69 based on the data collected by the Korea National Statistical Office, whose height and shoulder width are summarized on average.

Pathfinder program involves the children, grown-ups and the elderly classified on the basis of height, shoulder width. As shown in Table 2, the walking speed was input as variable based on relevant data regarding the children, grown-ups and the elderly.[12][13]

Table 2. Occupants' walking speed and bodily size

Occupant type(per person)	walking speed(m/s)	height(mm)	shoulder width(mm)
Children	0.77 [14]	1,419	307
the elderly	0.92 [15]	1,584	365
grown-ups	1.19 [16]	1,649	376

3. Evacuation scenario

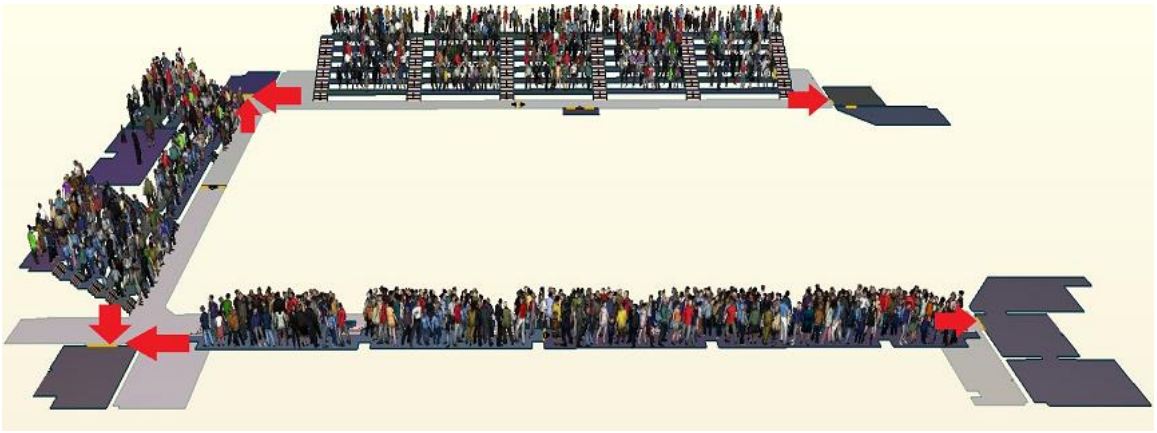
Table 3 shows that possible evacuation time is set to be 2 minutes for occupants hardly getting used to evacuation path of leisure sports center based on possible evacuation time described in 3-B of [Separate Table 1] of fire protection facility's performance-based design method and criteria. This is applicable to situation where instructions may be delivered vocally through broadcasting of control room featuring CCTV in fire protection center or may orally be provided by trained employee so that all occupants may recognize such instruction. The evacuation structure features 2nd floor which is connected to stair room allowing evacuees to reach 1st floor by leaving the closed fire doors open. When evacuees reach the 1st floor by using stairs, evacuation-induced lamps will guide evacuees to get to each of the exit doors and successfully be evacuated.

Table 3. Possible evacuation time[17]

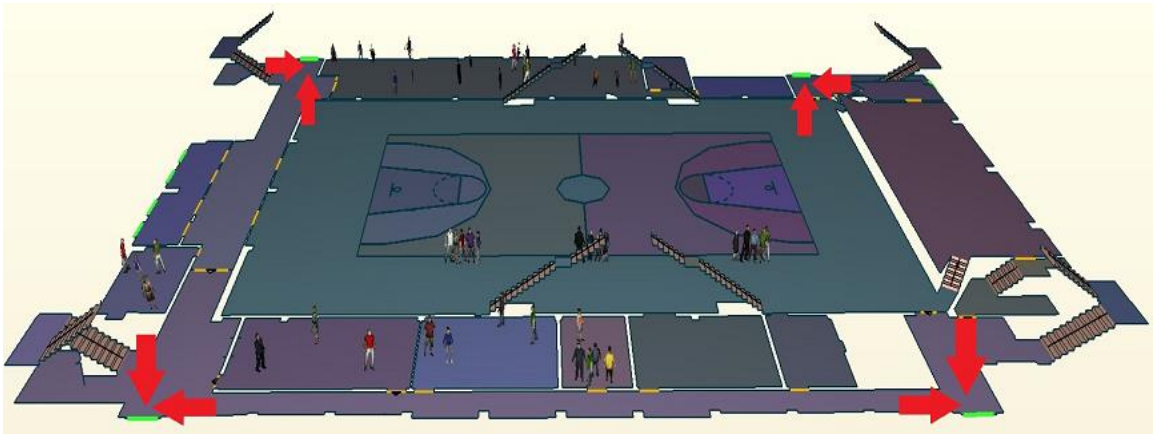
Usage	Possible evacuation time
store, museum, leisure sports center, other cultural facilities (Occupants are constantly aware but hardly familiar with inner facilities of the building, alarm and evacuation path)	less than 2 Min.

Fig. 2 shows that the occupants on the 2nd floor comprise 50% of grown-ups, 30% of children and 20% of senior members. The fitness room on the 1st floor features children, the elderly and grown-ups, while the remnant is set to be grown-ups. It took a man 63.8 seconds to walk to exit door on the 1st floor from the farthest point of the stand on the 2nd floor. In case fire broke out triggering simultaneous evacuation involving about 1,000 occupants, it may be knowable that bottleneck phenomenon at the entrance of stair area could quite delay evacuation. The study involved evacuation simulation program to identify evacuation time to be spent under the four case scenarios involving evacuees' movement towards 1st floor from 2nd floor.

Figure 2.Occupants by floor and evacuation path



(a) Occupants on the 2nf floor and entrance at stair area



(b) Occupants on the 1st floor and entrance and exit area

Scenario		Composition
When occupants on the 2nd floor, alarmed against fire, are successfully evacuated by walking down stairs featuring fire doors while avoiding risk posed by handrail positioned in the middle of the stand and successfully reaching hallway on the 1st floor towards exit	Scenario 1	simultaneous evacuation involving children, the elderly and grown-ups
	Scenario 2	sequential evacuation involving children, the elderly and grown-ups with time interval being set at 10 seconds
	Scenario 3	sequential evacuation involving children, the elderly and grown-ups with time interval being set at 20 seconds
	Scenario 4	equential evacuation involving children, the elderly and grown-ups with time interval being set at 30 seconds

4. Result and analysis

Figure 3. Evacuation state around area prone to bottleneck on the 2nd floor

(a) bottleneck around stairs of the stand

(b) bottleneck around the entrance of fire doors

The result shows that grown-ups were the quickest to be evacuated in the face of fire outbreak, followed by children and the elderly. The occupants comprised 50% of grown-ups representing the highest share of event seers, 30% of children and 20% of the elderly. Fig. 3 shows that while the grown-ups turned out to be the fastest in evacuation, bottleneck caused by narrow stairs along the aisle of the stand was delaying the evacuation. In addition, the bottleneck revealed around fire doors at the entrance of stair area was delaying evacuation a lot.

To resolve such bottleneck phenomenon, scenario was created to carry out evacuation with time interval being set according to age in addition to simultaneous evacuation.

The evacuees comprise children, the elderly and grown-ups, leading to slight difference in walking pace and height among them. Scenario 1, which set response time and recognition time at 30 seconds after the outbreak of fire, shows that all occupants were evacuated simultaneously. Such simultaneous evacuation result is shown in Table 4. In the course of evacuation, the fact is that while grown-ups walked fast enough, children and the elderly were not able to do that, leading to bottleneck around the stair area on the stand and entrance of fire doors.

Table 4. Result of scenario 1

Category	Children	the Elderly	Grown-ups
Evacuation time (s)	334.1	**334.6**	329.2

As the evacuees comprise children, the elderly and adults, slight difference was revealed in walking pace and height among them. Scenario 2, which set response time and recognition time at 30 seconds, shows that while children were evacuated immediately, it took the elderly 40 seconds (10 seconds later) to be evacuated and grown-ups 50 seconds (20 seconds later) to be evacuated. Such sequential evacuation result is detailed in Table 5.

Table 5.Result of scenario 2

Category	Children	the Elderly	Adult
Evacuation time(s)	350.7	**351.8**	348.1

As the evacuees comprise children, the elderly and adults, slight difference was revealed in walking pace and height among them. Scenario 3, which set response time and recognition time at 30 seconds, shows that while children were evacuated immediately, it took the elderly and adults 50 seconds (20 seconds later) and 70 seconds

(40 seconds later) to be evacuated respectively. Such sequential evacuation result is shown in Table 6.

Table 6. Result of scenario 3

Category	Children	the Elderly	Adults
Evacuation time(s)	**331.4**	327.4	325.1

As the evacuees comprise children, the elderly and adults, slight difference was revealed in walking pace and height among them. Scenario 3 , which set response time and recognition time at 30 seconds, shows that while children were evacuated immediately, it took the elderly and adults 60 seconds (30 seconds later) and 90 seconds (60 seconds later) to be evacuated respectively. Such sequential evacuation result is shown in Table 7

Table 7. Result of scenario 4

Category	Children	the Elderly	Adult
Evacuation time (s)	315.5	**320.4**	313.6tio

The above results show that under the sequential evacuation scenario such as scenario 1, 2 and 4, the elderly were the slowest to be evacuated. Under scenario 3, it was revealed that children were the slowest to be evacuated, though there was no significant difference from the evacuation time of the elderly. Under scenario 4 which set sequential evacuation interval at 30 seconds, it turned out that it took the shortest time to complete evacuation. This shows that to save evacuation time, it is better to evacuate people slowest to walk in the first place and sequentially carry out evacuation in certain space of time under the control of fire safety supervisor. Additionallyconsidering that indoor gymnasium inherently could lead to bottleneck phenomenon in the event of outbreak of fire, it is necessary to implement sequential and simultaneous evacuation simulations and if sequential evacuation has turned out to be better, it is necessary to decide on age-based priority, prepare tailored manual to each of the gymnasiums and accordingly implement fire drills.

5. Conclusion

The study analyzed age-based simultaneous and sequential evacuation time in the event of fire outbreak to indoor gymnasium. The result shows:

(1) It took 334.8 seconds to complete simultaneous evacuation involving children, the elderly and adults. Bottleneck phenomenon was shown around stairs of the stand and entrance of fire doors as the children and the elderly, compared with adults, were slow to be evacuated in the course of evacuation.

(2) Under age-based sequential evacuation scenario which set interval at 10 seconds and set 1st priority on children, followed by the elderly and adults, it was revealed that adults were the quickest to be evacuated, followed by children and the elderly and that it took a total of 352 seconds to complete evacuation.

(3) Under age-based sequential evacuation scenario which set interval at 20 seconds and set 1st priority on children, followed by the elderly and adults, it was revealed that adults were the quickest to be evacuated, followed by the elderly and children and that it took a total of 325.1 seconds to complete the evacuation.

(4) Under age-based sequential evacuation scenario which set interval at 30 seconds and set 1st priority on children, followed by the elderly and adults, it was revealed that adults were the quickest to be evacuated, followed by the elderly and children and that it took a total of 313.6 seconds to complete the evacuation.

Considering the above results, it may be concluded that in order to save evacuation time, it will be better to set 1st priority on people slower to walk and set interval at 30 seconds for evacuation. Given that indoor gymnasium inherently could lead to bottleneck phenomenon, it is necessary to prepare manual tailored to each of the

gymnasiums based on evacuation simulation.

This study reveals that under the age-based fire evacuation scenarios, bottleneck phenomenon inevitably followed and delayed evacuation process. The bottleneck was particularly notable in stair area of the stand and around the entrance of fire doors, raising the need to alter fire door size and width and height of stairs on the stand so that bottleneck phenomenon may be forestalled.

References

A. Lim, Y. R. (2018). Study on comparison of evacuation results based on pre-informed recognition factors in the face of fire outbreak to subway station in large cities, M.A. thesis, Hanyang University Graduate School, Department of Civil Engineering, 1.

B. Lee, S. W. (2020). Study on evacuation safety in open air evacuation safety area, M.A. thesis, City Science Graduate School at University of Seoul, Department of Fire & Disaster Prevention Engineering, 12.

C. Lee, C. H. (2019). Study on safety verification of evacuation facilities based on evacuation simulation, M.A. thesis, Graduate School of Gachon University, Department of Fire Protection Engineering, 1.

D. Lee, J. Y. (2020). Indoor fire evacuation simulation considering spread of fire, M.A. thesis, Graduate School at University of Seoul, Department of Geoinformatic Engineering, 5.

E. Kim, J. H. (2009). Study on ways of upgrading evacuation performance in the face of emergency to large-sized indoor gymnasium, M.A. thesis, Graduate School of Yeungnam University, Department of Architecture, 2.

F. Cho, J. D. (2002). Study on fire safety performance policy of Dome-shaped indoor gymnasium, M.A. thesis, Industry Information Graduate School at Kyonggi University, Department of Fire, 1.

G. Cho,S. J. (2014). Application of evacuation simulation for safety analysis of professional sports stadium,Ph.D dissertation, Graduate School of Kookmin University, Department of Physical Education, 5.

H. Kim, G. H. (2011). Study on evacuation safety assessment based on ways of utilizing indoor gymnasium, M.A. thesis, Graduate School of Science and Technology at Kyungpook National University, Department of Architectual Engineering, 73.

I. Cheon, I. B. (2019). Calculating evacuation time for medical welfare center for the elderly based on FDS and Pathfinder, M.A. thesis, graduate School of Inha University, Department of ET & ST Convergence, 8.

J. Kim, J. Y. (2015). Case analysis of fire simulation FDS and evacuation simulation Pathfinder, The Korean Society of Business Venturing, 255.

K. National Law Information Center, (2017). 3- in Mark Separately 1 of performance-based design method and criteria including fire protection facility.

L. Korea National Statistical Office, (male)investigation of Koreans' body size,(http://kosis.kr/statHtml/statHtml.do?orgId=115&tblId=TX_115190170&conn_path=I2)

M. Korea National Statistical Office, (female)nvestigation of Koreans' body size(female),(http://kosis.kr/statHtml/statHtml.do?orgId=115&tblId=TX_115190171&conn_path=I2)

N. Satoh, E. at al. (2006). Investigation of converted walking distance considering resistance of topographical features and changes in physical strength by age, Journal of Architecture Planning, 133-139.

O. SFPE. (2013). The SFPE Handbook of Fire Protection Engineering,5th editionp.2216.

P. Stephanie Studenski. at al. (2011).Gait Speed and Survival in Older Adults, American Medical Association, 50-51.

Q. National Law Information Center. (2017). 3-Na in Mark Separately 1 of performance-based design method and criteria including fire protection facility.