Research Article

Determination of Appropriate area University Labotatories In Consideration of Extinction Coefficient

Seo- Young Kim[1], Ha-Sung Kong[*2]

[1*2]Fire and Disaster Prevention, Woosuk University Graduate Sch., WANJU, Korea
ppiony@naver.com[1], 119wsu@naver.com [2]

Article History: Received: 11 January 2021; Accepted: 27 February 2021; Published online: 5 April 2021

Abstract: This study calculated the appropriate area of university laboratories which shall allow 40 students to evacuate in the shortest time frame when they evacuate at the walking speed per extinction coefficient of smoke to be created upon outbreak of fire.In the case where the floor area was 600㎡, the required safe egress time (RSET) for the total 40 students was 48.3 seconds when extinction coefficient was $0.3m^{-1}$, 52.6 sec when extinction coefficient was $0.5m^{-1}$, and 54.3 sec when extinction coefficient was $1.0m^{-1}$. In the case where the floor area was reduced to 300㎡, half of the first case, the RSET for the total 40 students was 50.0 sec when extinction coefficient was $0.3m^{-1}$, 56.4 sec when extinction coefficient was $0.5m^{-1}$, and 54.1 sec when extinction coefficient was $1.0m^{-1}$, showing the result that RSET of all the students was rather elongated when extinction coefficient was $0.3m^{-1}$ and $0.5m^{-1}$ respectively due to bottleneck caused by increase in population density even though the exit distance was shortened. In the case where the floor area was increased to 1200㎡, twice of the first case, RSET of all the levels of extinction coefficient was elongated due to increase in exit distance. As result of the experiments with different size of floor areas, the shortest RSET of all the students was found with 540㎡ of floor area. In conclusion, it was found that the RSET for all the people in the lab shall be shortest when the floor area was appropriate.

Keywords:extinction coefficient, university laboratory, appropriate area, walking speed, bottleneck

1. Introduction

There are lot of risk factors in laboratories. Risk factors include physical, mechanical, chemical, and biological risks, and casualties are occurring due to explosion, poisoning, fire etc. [1]. There was an explosion in the laboratory in one university on December 27, 2019, and 4 students were injured by the accident [2]. There are lot of possibilities of accident in laboratories that can lead to casualties. There have been 379 cases of laboratory accidents in 140 institutions in 2018, and 308 cases of laboratory accidents have happened in universities, which represent larger portion of the entire laboratory accidents

[3,18]. The accidents were comprised of cuts, squeezes, explosion, fire, etc. [4]. There are many kinds of accidents in laboratories, but when a fire erupts in a laboratory, it is very likely that it can end up in a large fire because of many chemical products and flammable materials that exist in laboratories. Also, the smoke created at the beginning of a fire can entrap people remaining indoor and limit visibility of the entrapped people, thereby leading them to death. The casualties caused by smoke during fire accidents amounted to 554 and 258 in 2019 and January through May 2020 respectively and among the casualties, deaths amounted to 178 and 143 in 2019 and January through May 2020 respectively [5,17]. As can be understood in these data, the smoke during fire accidents not only hinders evacuation but also threatens lives of many people.

When reviewing the existing studies, Young Hoon Bae et al. (2014) found that when there was smoke in basement, the walking speed of both individuals and groups were decreased. But it was also found the group evacuation time was decreased due to decrease in distance between evacuating individuals. Therefore, the study concluded that analysis of characteristics in walking behaviors at the time of group evacuation through analysis of distance among evacuating individuals.Min Hyuk Lee et al. (2019)[7]conducted microscopic simulation for the groups of 100, 200, 300, and 400 people. As result of the simulations, the study concluded there can be some deaths if the size of evacuating group is larger than 300 people. For designing of evacuation safety, Dong Koo Suh et al. (2010)[8] derived the Korean characteristics in evacuation behaviors after analyzing the walking speed at the time of group formation during evacuation. Jung Soo Lee et al. (2012)[9] analyzed the influence of evacuating density, which is dependent on width of corridor and stairway, over evacuating behaviors and analyzed the relationships among variables influencing psychological factors. The study concluded that the most influential factor was found to be rather cognitive than physical. Jae Ho Moon et al. (2010)[10] analyzed the influence of width of passages and density of evacuating people over evacuating duration.Young Hoon Bae et al. (2014) and Dong Koo et al. (2010)conducted analysis of walking speed at the time of group formation. Young Hoon Bae et al. (2014) and Min Hyung Lee et al. (2019) analyzed how evacuation is influenced by the smoke that occurs during fire accident. Jung Soo Lee et al. (2012) and Jae Ho Moon et al. (2010) studied influence of passage width and density of evacuating people over evacuation within facilities of universities.

As seen in the above, majority of studies have determined appropriate number of people that can be accommodated in a building through analysis of walking speed at the time of group formation, analysis of changes in evacuating duration depending on width of corridor and stairway,or analysis of evacuating duration depending on number of evacuating people.However, there is few which determines appropriate floor area by finding evacuation duration depending on sizes of floor area.

This study is intended to determine appropriate floor area of university laboratories that allows evacuation as prompt as possible by measuring evacuation duration while conducting evacuation at the walking speed depending upon different levels of extinction coefficient of smoke that forms during fire accidents

2. Theoretical Review

Extinction coefficient is a measurement that indicates density of smoke along the decrease of the amount of light. Smoke coming out of fire blocks the sight of evacuating people, and thereby entraps people inside a building and restricts their behaviors. Limitation of visibility meter indirectly causes death but is still fatal [11].

Visibility meter refers to the distance visible to the eye [12]. Smoke coming out of fire blocks eyesight, and the visibility is more limited with more dense smoke. Visibility meter is inversely proportionate to extinction coefficient. The change in visibility meter depending upon extinction coefficient and the corresponding conditions are shown in Table 1.

Table 1. Conditions Corresponding to Extinction Coefficient and Visibility Meter

Extinction Coefficient	Visibility Meter(m)	Condition
0.1	20~30	The level that smoke detector begins to detect
0.3	5	The level that can deter evacuation of people
0.5	1~3	The level that shall allow no visibility
1.0	0.2~0.5	At the peak of smoke
30	-	The smoke coming out of burning space

3. Evacuation Simulation

3.1 Selection of Simulation Site

We conducted analysis on the hypothesis that a building with laboratories inside was set on fire. There were 6 rooms in the building - 1 special experimental lab, 2 labs with jet cooler system, lab #2 for experiment of construction materials including thermo-hygrostat room, lab #1for experiment of construction materials. There was 1 entrancethat can be used to evacuate out of the building and the area of the entire building was 600 ㎡ (Figure 1).

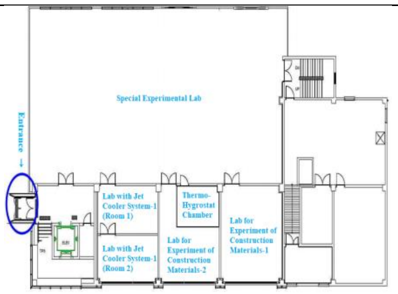
Floor Plan	Floor Area	Evacuation Route
	600m²	Entrance1

Figure 1. Floor Plan of Simulation Site

3.2Program Input Value

For the purpose of determining the appropriate floor area of university laboratories, we selected the types of occupants remaining inside, walking speed, shoulder width, door width, and corridor width as the laboratories in consideration of the laboratories located in university, and input walking speeds corresponding to different levels of extinction coefficients applicable during fire accident for male and female separately. Shoulder with were input from the statistics on Korean Physical Sizes for Male and Female in their 20s. We input the actual sizes of width for doors and corridor.

Table 2. Evacuation Input Value

<table>
<tr><th colspan="2">Input Variable</th><th colspan="3">Input Value</th><th>Reason</th></tr>
<tr><td colspan="2">Occupant Type</td><td colspan="3">Male and female in their 20s</td><td>In consideration of university lab site</td></tr>
<tr><td colspan="2" rowspan="5">Walking Speed</td><td rowspan="2">Extinction Coefficient (m^{-1})</td><td colspan="2">Walking Speed (m/s)</td><td rowspan="5">Applied walking speed corresponding to extinction coefficients during fire accident [13]</td></tr>
<tr><td>male</td><td>Female</td></tr>
<tr><td>0.3</td><td>0.87</td><td>0.85</td></tr>
<tr><td>0.5</td><td>0.79</td><td>0.83</td></tr>
<tr><td>1.0</td><td>0.77</td><td>0.76</td></tr>
<tr><td colspan="2">Shoulder Width</td><td colspan="3">Male: 40.2cm [14]
Female: 35.8cm [15]</td><td>Applied the sizes from the statistics of "Size Korea (2015)"</td></tr>
<tr><td rowspan="2">Width</td><td>Corridor</td><td colspan="3">120cm</td><td rowspan="2">Actual sizes of the building</td></tr>
<tr><td>Door</td><td colspan="3">180cm</td></tr>
</table>

3.3 Criteria for Determination OD Number of Occupants

Most of the college classes are conducted in separate grade. When using classroom classrooms can e used only according to predetermined class schedules. Therefore, we used 40 people – which id the average class size of private university– as the number of occupants and set the ratio of male and female as 50 to 50 as sown in Table 3.

Table 3. Evacuation Input Value

Number of Occupants	Occupant type	Numbers(%)
40	Male	20(50%)
	Female	20(50%)

3.4 Evacuation Scenario Composition

We set up 4 scenarios as shown in Table 3. For scenario 1, we have calculated Required Safe Egress Time (RSET), based on the actual floor area 600 ㎡ of the actual site of this model, by applying the walking speeds of male and female corresponding to extinction coefficient during fire accident. For scenario 2, we have calculated RSET based on 50% of the floor area of the actual site, which is 300m^2. For scenario 3, we have calculated RSET based on 200% of the floor area of the actual site, which is 1200m^2. For scenario 4, we have calculated RSET after finding out appropriate floor area.

Table 4. Scenario Composition

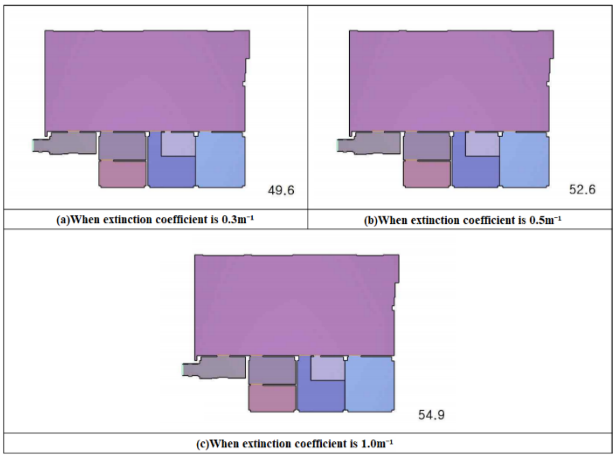
Scenario	Contents
1	Based on the floor area of 600 ㎡, we calculated RSET of all occupants corresponding to extinction coefficient during fire accident.
2	Based on the floor area of 300 ㎡, we calculated RSET of all occupants corresponding to extinction coefficient during fire accident.
3	Based on the floor area of 1200 ㎡, we calculated RSET of all occupants corresponding to extinction coefficient during fire accident.
4	We have calculated RSET after finding out appropriate floor area.

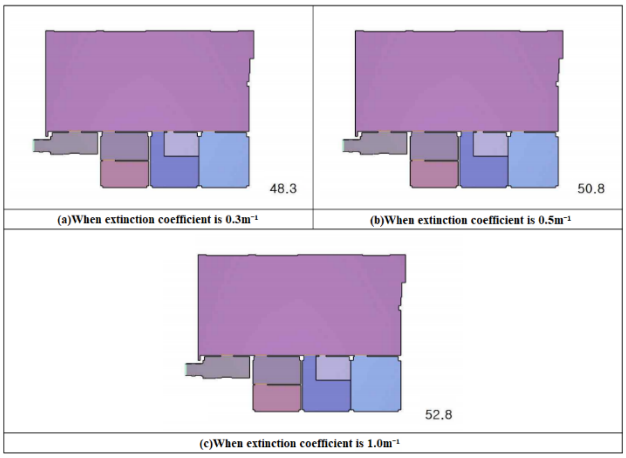
3.5Evacuation Basis

Occupants are all awake and are familiar with structure of the building, alarming, and evacuation routes. Since the building uses fire alarm system and occupants should evacuate under the control of guidance, evacuation should be completed in less than 4 minutes as shown in Table 5[16]. However, the results of this simulation found that the evacuations of all the scenarios were completed in less than 4 minutes. Therefore, we found the floor area that allows evacuation toTable 2. Determination of Occupants and Occupant Compositionbe completed faster than the floor area of 600 ㎡, and determine it as the appropriate area for evacuation.

Table 5. Duration Available for Evacuation

Occupancy	Available Evacuation Time
Occupants are always awake and familiar with building structure, alarm system, and evacuation routes.	Under 4 minutes





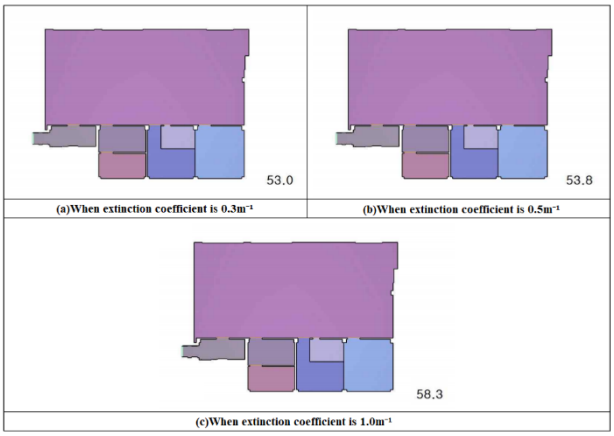
4. Results and Reviews

4.1Scenario 1

When the floor area was 600 ㎡, the time elapsed for completion of evacuation is shown in Figure 2. The time elapsed for completion of evacuationfor the extinction coefficient of $0.3m^{-1}$was 49.6 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $0.5m^{-1}$ was 52.6 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $1.0m^{-1}$ was 55.5 seconds. As walking speeds get slower with more dense extinction coefficient, the time elapsed for completion of evacuation was elongated accordingly.

Figure 2. Time Elapsed for Completion of Evacuation (Scenario 1)

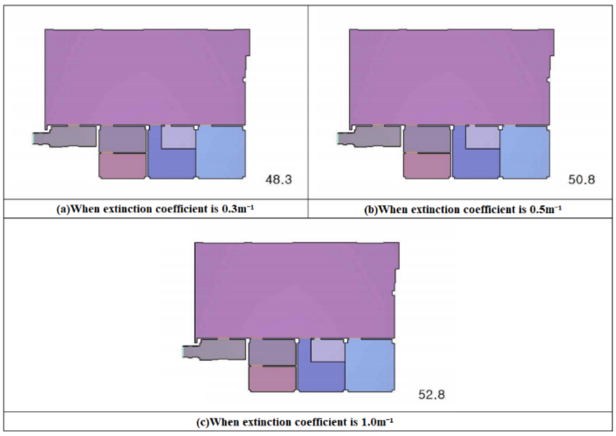
(a) When extinction coefficient is $0.3m^{-1}$,
(b) When extinction coefficient is $0.5m^{-1}$,
(c) When extinction coefficient is $1.0m^{-1}$,



(d) When extinction coefficient is $0.3m^{-1}$,
(e) When extinction coefficient is $0.5m^{-1}$,
(f) When extinction coefficient is $1.0m^{-1}$**4.2Scenario 2**When the floor area was 300 ㎡, 50% of scenario 1, the time elapsed for completion of evacuation is shown in Figure 3. The time elapsed for completion of

evacuationfor the extinction coefficient of $0.3m^{-1}$ was 53.0 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $0.5m^{-1}$ was 54.0 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $1.0m^{-1}$ was 58.3 seconds. As walking speeds get slower with more dense extinction coefficient, the time elapsed for completion of evacuation was elongated accordingly.

Figure 3. Time Elapsed for Completion of Evacuation (Scenario 2).
(a) When extinction coefficient is $0.3m^{-1}$,

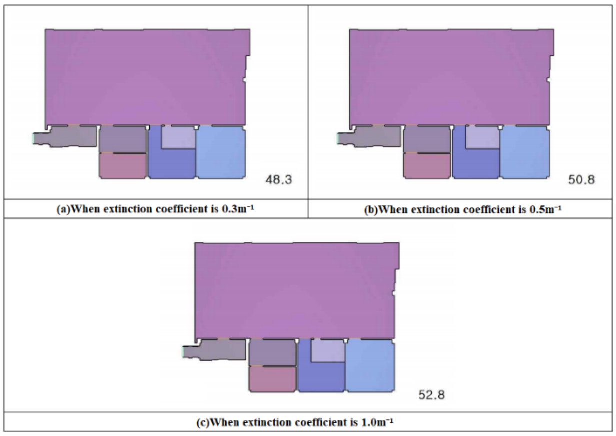


(b) When extinction coefficient is $0.5m^{-1}$,
(c) When extinction coefficient is $1.0m^{-1}$

4.3Scenario 3

When the floor area was 1200 ㎡, 200% of scenario 1, the time elapsed for completion of evacuation is shown in Figure 4. The time elapsed for completion of evacuationfor the extinction coefficient of $0.3m^{-1}$ was 60.8 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $0.5m^{-1}$ was 64.0 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $1.0m^{-1}$ was 67.1 seconds. As walking speeds get slower with more dense extinction coefficient, the time elapsed for completion of evacuation was elongated accordingly.

Figure 4. Time Elapsed for Completion of Evacuation (Scenario 3)
(a) When extinction coefficient is $0.3m^{-1}$,
(b) When extinction coefficient is $0.5m^{-1}$,
(c) When extinction coefficient is $1.0m^{-1}$



4.4Scenario 4

As result of simulations of several floor areas for determination of more appropriate floor area than the actual floor area of the building, we found the time elapsed for completion of evacuation was shortest when the floor area was 540 ㎡.As shown in Figure 5, this scenario showed the shortest time for completion of evacuation, and the time elapsed for completion of evacuationfor the extinction coefficient of $0.3m^{-1}$ was 48.3 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $0.5m^{-1}$ was 50.8 seconds, and the time elapsed for completion of evacuationfor the extinction coefficient of $1.0m^{-1}$ was 52.8 seconds.

Figure 5. Time Elapsed for Completion of Evacuation (Scenario 4)
(a) When extinction coefficient is $0.3m^{-1}$,
(b) When extinction coefficient is $0.5m^{-1}$,
(c) When extinction coefficient is $1.0m^{-1}$

We have compared 4 scenarios in Table 6. When we compared the scenario 1 (300 ㎡) and 2 (600 ㎡), RSETs of all the occupants for scenario 1 were longer than those of scenario 2 due to the bottleneck caused by higher population density even though the evacuation distance was shorter than scenario 2. In case of the scenario 3, which has the floor area 2 times larger than the scenario 2, RSETs of all the occupants were longest than any other scenarios due to increased evacuation distance. As result of repeated simulations through adjustment of floor area, we found that RSETs of all the occupants were shortest than any other scenario when the floor area was 540 ㎡. Consequently, it was found that RSETs of all the occupants can be minimized when the floor area is appropriate for the total number of occupants.

Table 6. Comparison of RSETs for Different Scenarios& Extinction Coefficients

Floor Area(m^2)	Extinction Coefficient (m^{-1})	RSET(s) of All the Occupants	Maximum Evacuation Meter (m)	Average Evacuation Meter (m)[1)]
300	0.3	53.0	31.1	29.7
	0.5	53.8	29.8	
	1.0	58.3	28.2	
600	0.3	49.6	38.3	38.3
	0.5	52.6	39.1	
	1.0	54.9	37.6	
1200	0.3	60.8	52.0	51.3
	0.5	64.0	52.2	
	1.0	67.1	49.8	
540	0.3	48.3	36.4	37.3

5. Conclusion

In this study, we have developed scenarios to find appropriate floor area that allows shortest RSETs for all occupants when occupants evacuate at walking speed corresponding to different level of extinction coefficients. Comparisons of the time elapsed for completion of evacuation when evacuated at the walking speed corresponding to different levels of extinction coefficients are as follows:

(1) When comparing scenario 1 and 2, RSET of scenario 2 was longer. RSET was 6.85% longer when extinction coefficient was $0.3m^{-1}$, and 2.28% longer when extinction coefficient was $0.5m^{-1}$, and 6.19% longer when extinction coefficient was $1.0m^{-1}$.

(2) When comparing scenario 1 and 3, we can see RSET of scenario 3 was longer.RSET of scenario 3 was 22.58% longer when extinction coefficient was $0.3m^{-1}$, and 21.67% longer when extinction coefficient was $0.5m^{-1}$, and 22.22% longer when extinction coefficient was $1.0m^{-1}$.

(3) When comparing scenario 1 and 4, we can see RSET of scenario 4 was shorter. RSET of scenario 4 was 2.62% shorter when extinction coefficient was $0.3m^{-1}$, and 3.42% shorter when extinction coefficient was $0.5m^{-1}$, and 3.82% shorter when extinction coefficient was $1.0m^{-1}$. Therefore, it was determined as the appropriate floor area that allows evacuation as prompt as possible.

At the beginning of the simulation, we expected that smaller floor area shall allow shorter evacuation of all occupants. However, as result of the simulations, we found that scenario 1 resulted in longer RSET due to bottleneck caused by more dense population even though scenario 1 had a smaller floor area.Consequently, we found out that RSET can be minimized when floor area is appropriate for total number of occupants.Meanwhile, as the subject of future study, analysis of change in RSET corresponding to changes in illumination intensity shall also be worthwhile.

References

1. Y.J.Chung, Risk of Accidents Analyzed in the Laboratory of the University, Journal of the Korean Society of Hazard Mitigation, Vol.12, No.6, p.191, 2012

2. The Kyunghyang Shinmun, '4 Students Injured by Explosion Occurred in the Laboratory of Gyungbuk National University', 2019.12.27.
3. Ministry of Science and ICT, Korea Research Institute of Bioscience and Biotechnology, NatioReserch Safety Headquarters, 2019 Research on Safety Control in Laboratories, p.146
4. National Research Safety Information System, Safety Control in Laboratories, Cases of Laboratory Accidents, (https://www.labs.go.kr/brdartcl /boardarticleList.do?brd_id=BDIDX_9Vq30r1y1m6G4U2YFEDqG5&menu_nix=N63Q9ws5)
5. National Fire Data System, Statistics on Fire Accidents, Analysis of Trend in Fire Accidents, (https://www.nfds.go.kr/stat/trend.do)
6. [6] Y.H.Bae, S.H.Lee, J.H.Choi, W.H.Hong, Analysis on Walking Speed of Crowd According to Smoke in Underground Evacuation Situation, Journal of the Architectural Institute of Korea, Vol.34, No.1, p.216 ,2014
7. M.H.Lee, J.Y.Lee, C.M.Jun, Agent-based Evacuation Model considering Smoke Spreading, Journal of Korean Society for Geospatial Information Science, Vol.27, No.6, p.50 ,2019
8. D.G.Seo, E.K.Hwong, Y.J.Kwon, An Investigation Study on the Walking Speed of Crowd for Egress Safety of PBD ,Journal of the Architectural Institute of Korea Planning & Design, Vol.26, No.12, p.99 ,2010
9. J.S.Lee, H.S.Kwon, Evacuation Behaviors under the Corridor and Stair Width Variations in Evacuation Experiments, Journal of the Korea Academia-Industrial cooperation Society, Vol.13, No.5, pp.2374-2381 ,2012
10. --
    1) Average Evacuation Meters = (31.1+29.8+28.2) ÷ 3 = 29.7m
11. J.S.Lee, J.H.Mun, A Study on the Evacuation Time According to the Width of Corridor, Stair and Density of Evacuee in University Education Facilities, Korea Citation Index, Vol.17, No.1, p.14 ,2010
12. S.H.Lee, Analysis on Extinction Coefficient and Evacuation Descent Spped Within Smoke layers in a Staircase, thesis of master’s degree at Gyungbuk National University, p.34, 2012
13. The National Institute of the Korean Language, Standard Korean Encyclopedia, (https://stdict.korean.go.kr/main/main.do)
14. S.H.Lee, J.H.Choi, W.H.Hong, Analysis on Vertical Walking Speed according to Extinction Coefficient within Smoke Layers in a Staircase, Journal of the Architectural Institute of Korea Planning & Design, Vol.27, No.11, p.364, 2011
15. Statistics Korea, Korean Body Size Survey: 120 areas of statistics (male), (http://kosis.kr/statHtml/statHtml.do?orgId=115&tblId=TX_115190170&conn_path=I2)
16. Statistics Korea, Korean Body Size Survey: 120 areas of statistics (female), (http://kosis.kr/statHtml/statHtml.do?orgId=115&tblId=TX_115190171&conn_path=I2)
17. Korea Ministry of Government Legislation, 「Performance-oriented design methods and criteria such as fire protection system」 [Appendix 1] No.3 (나)26 July 2017. Enforcement
18. Garidzirai, R., Meyer, D. F., & Muzindutsi, P. F. (2019). The impact of economic sectors on local economic development (led): the case of the Capricorn region, Limpopo province, South Africa. International Journal of economics and finance studies, 11(2), 20-35.
19. Hove, T. M., & Troskie, T. (2019). FAMILY BUSINESS OWNERS’PERCEPTIONS ON SEEKING ESTATE PLANNING ASSISTANCE. International Journal of Economics and Finance Studies, 11(2), 55-71.