EMERGENCY BROADCAST SOUND AND SPEECH INTELLIGIBILITY IN FIRE SAFETY ZONES OF HIGH-RISE BUILDINGS

Jeong-ho Jeong[1*]
[1] Fire Insurers Laboratories of Korea, Yeoju-si, Republic of Korea

ABSTRACT

With the increase in construction of high-rise buildings, the installation of fire safety zones for the safe evacuation of residents has become mandatory in Korea. In fire safety zones, an emergency broadcasting system must be installed to announce the fire situation and guide the safe evacuation of residents. The fire safety zone was constructed using a non-combustible material. However, non-combustible materials usually reflect sound energy in space. Emergency broadcast sounds reverberate in spaces with sound reflective materials, making it difficult to understand the meaning of the broadcasted message. In this study, the room acoustic characteristics in the fire safety zones of a high-rise building, represented by the reverberation time and speech transmission index, were predicted using a room acoustic simulation method and evaluation of speech intelligibility. The results of the acoustic characteristic prediction of the safety zone indicated that the space exhibited a long reverberation that resulted in low speech intelligibility, making it difficult to clearly transmit emergency broadcast messages. To deliver a clear emergency broadcast message in a safety zone, it is necessary to use inorganic sound-absorbing materials. In addition, it is necessary to establish guidelines for the regulation of speech transmission indices in emergency broadcasting systems.

Keywords: *emergency broadcasting*, *fire safety zone, speech intelligibility, high-rise buildings, room acoustics*

1. INTRODUCTION

In Korea, the construction of high-rise buildings has been increasing. The installation of fire safety zones is mandatory to safely evacuate occupants in the event of a disaster in a high-rise building [1]. In fire safety zones, alarm and communication facilities that enable emergency contact with management offices or disaster prevention centres and emergency broadcasting systems are installed and operated. It is stipulated that the interior finishing materials of evacuation safety zones should be installed using non-combustible materials.

In general, non-combustible materials tend to have a hard surface composed of inorganic materials; therefore, they do not absorb and reflect sound on the surface. If an emergency broadcasting system is operated while the fire safety area built of non-combustible materials is closed, difficulties in clear communication are expected due to sound reverberation. In addition, when an occupant evacuates to an evacuation safety zone, background noise may increase, and emergency broadcast sounds may not be delivered at a sufficient volume.

In this study, a room acoustic prediction method was used to evaluate whether emergency broadcasting sounds were clearly transmitted in a closed evacuation safety area built with non-combustible materials. Five types of virtual evacuation safety zones were configured by size and type, non-combustible materials were input as internal finishing materials, and sound prediction was performed under the conditions wherein speakers were installed according to the emergency broadcasting facility standards.

2. FIRE SAFETY ZONE IN HIGH-RISE BUILDING

The installation, operation codes, and scale of evacuation safety zones are stipulated in the Nation Fire Safety Codes for High-rise Buildings (NFSC 604) [2] Firefighting Facilities for Fire Safety Zones. Additionally, materials that are not specifically regulated should be installed according to individual fire safety standards. The area of the evacuation

[*]Corresponding author: *jhjeong92@gmail.com.*

safety zone was calculated using Equation (1), and the occupant density was specified for each type of use-case of the building.

Area of Fire Safety Zone = (Number of occupants on the upper floor of the fire safety zone × 0.5) × 0.28 m^2 (1)

Smoke control equipment, evacuation guidance lines, emergency lighting, portable emergency lighting, and lifesaving equipment should be installed in evacuation safety areas. Additionally, warning and communication facilities must be installed.

The fire safety zone is covered with hard, non-combustible materials that produce reverberations. If the sound reverberates, it becomes difficult to clearly hear the sound transmitted through the emergency broadcasting system. Additionally, it gets muffled in the conversations that occur among residents who are evacuated to the fire safety zone. When more occupants are evacuated to the safety evacuation zone, the background noise caused by the occupants' actions or conversations increases because of the Lombard effect [3], making communication between occupants and the transmission of emergency broadcast messages more difficult. The difficulty in clear communication in the evacuation safety zones and in smooth delivery of emergency broadcast messages hinders the effective propagation of the emergency broadcast, thereby making it challenging to respond in the case of fire and other disastrous situations.

3. PREDICTION OF SPEECH TRANSMISSION INDEX IN FIRE SAFETY ZONES

Odeon 12 was used to predict and compare the degree of clear transmission of emergency broadcast messages from fire safety zones. As shown in Table 1, the fire safety zones to be predicted were set as five virtual spaces based on the number of people accommodated and the shape of the evacuation safety zone. The evacuation safety area was stipulated to be 0.28 m^2 per person, which can occupy 50% of the number of occupants. The evacuation safety zone for 1,000 people was classified in two types: a rectangular plane (Case 4) and a plane approximately equivalent to a square (Case 5). In the case of the rectangular plane in Case 4, the length of the long side is 40 m, and two emergency broadcasting speakers should be installed at 25 m intervals; the plane of Case 5 only required one speaker. The floor height of a typical office building is 4 m, and ceiling textures for finishing or sound-absorbing ceiling materials are installed in the building. The height was set as 4 m when no ceiling texture or sound-absorbing ceiling material was installed.

The interior finishing material used for the five models was a cement coating. For the ceiling, a gypsum board was considered as the basic condition, and the sound absorption characteristics of the glass-fibre-based ceiling finishing material were selected for comparison with the case in which the sound echo in the evacuation safety area was short. The sound from the emergency broadcasting speaker was set to 93 dBA. The characteristics of each frequency band of the sound source were flat, and 86 dB was set for each frequency band. The sound power level is the energy radiated from the sound source, and the sound heard at a point far from the sound source was evaluated as the sound pressure level (dB). The relationship between the sound power level and sound pressure level is as follows.

Table 1. Acoustic Simulation Setup for the Comparison of Speech Intelligibility of Fire Safety Zone

	Case 1	Case 2	Case 3	Case 4	Case 5
Capacity [person]	100	250	500	1,000	1,000
Size	4m × 7m	10m × 7m	20m × 7m	40m × 7m	20m × 14m
Number of speakers	1 EA	1 EA	1 EA	2 EA	1 EA

The RT20 (Reverberation Time), A-Weighted Sound Pressure Level, and sound transmission index (STI) were used as the evaluation indices. The STI is an index for evaluating the degree of distortion of the generated sound signal and is known to be affected by the level of background noise [4]. The room acoustic prediction was performed by varying the background noise level. The change in the intensity of the background noise was measured from 50 dBA, which is the background noise level of a general office space, under no background noise and when there was background noise to determine the acoustic characteristics of the fire safety zone itself. The background noise was increased at 10 dB intervals up to 90 dBA and compared.

The average values of the acoustic prediction results for the evacuation safety zone are summarised in Table 2. As the RT20 and A-weighted sound pressure levels of the emergency broadcast are not affected by background noise, only the results for the changes in ceiling sound absorption performance were compared.

Table 2. Predicted Room Acoustic Parameters of Fire Safety

Acoustic parameter		Case 1		Case 2		Case 3		Case 4		Case 5	
		Without Abs	With Abs	Without Abs	With Abs	Without Abs	With Abs	Without Abs	With Abs	Without Abs	With Abs
RT20 at 500 Hz		5.00 s	1.42 s	5.02 s	1.44 s	4.95 s	1.4 4s	5.30 s	1.83 s	4.99 s	1.79 s
SPL(A)		91.0 dB	84.9 dB	87.8 dB	81.1 dB	85.3 dB	78.3 dB	85.2 dB	78.5 dB	82.8 dB	75.6 dB
STI	No BGN	0.57	0.57	0.32	0.55	0.32	0.56	0.35	0.54	0.31	0.54
	BGN 50 dB	0.34	0.57	0.32	0.55	0.32	0.56	0.35	0.54	0.31	0.54
	BGN 60 dB	0.34	0.57	0.32	0.54	0.32	0.55	0.35	0.53	0.31	0.52
	BGN 70 dB	0.34	0.55	0.31	0.51	0.31	0.5	0.34	0.48	0.29	0.45
	BGN 80 dB	0.32	0.46	0.28	0.38	0.25	0.32	0.27	0.32	0.21	0.25
	BGN 00 dB	0.21	0.24	0.14	0.12	0.09	0.06	0.09	0.06	0.04	0.01

RT20 was found to be at 5 s in all five evacuation safety zones, in which sound absorption performance was not applied to the ceiling of the evacuation safety zone. When a glass-fibre-based ceiling material was applied, the reverberation time was shortened to about 1.42 s to 1.79 s. As the size of the fire safety zone increased, the reverberation time also increased.

The average sound pressure level of the emergency broadcast transmitted into the fire safety zone decreased as the size of the space increased, which may be because the number and output of emergency broadcasting speakers remained the same. However, as in Case 4, when two emergency broadcasting speakers were installed, the average sound pressure level was 2.4 dB higher than that in Case 5, even though they had the same scale. It was found that the average A-weighted sound pressure level of the emergency broadcast sound was lowered by 6.1 dB to 7.2 dB when the sound absorption performance of the fire safety zone was increased. This is because sound reverberation in space decreases as the sound absorption performance increases and the sound quickly diminishes and disappears.

When there is no background noise and materials with high sound absorption performance are not applied to the ceiling, except for Case 1 which is the smallest, the average value of the speech transmission index was less than 0.45 in the remaining four scales, corresponding to the "Poor" grade [5]. Considering background noise, the average speech transmission index was 0.3 in all cases. When the background noise increased, the average value of STI at the same background noise level decreased as the size of the fire safety zone increased.

The sound absorption performance of the ceiling was increased to improve the STI. The STI was more than 0.5 with no background noise or less than 60 dB, and it was found to be of a "Fair" level. When the background noise was 70 dB or more, the average STI was lowered to 0.3 or less, corresponding to a "Poor" level. When the background noise was extremely high, over 90 dB, the speech transmission index was rated as "Bad" with a rating of less than 0.3, irrespective of the increase in the sound absorption performance of the ceiling.

Table 2 compares the A-weighted sound pressure level distribution of emergency broadcast messages delivered to evacuation safety zones based on whether the absorbent materials were used. When sound-absorbing material was not applied, the sound pressure level distribution in the space was even because of the sound reflections. When the sound-absorbing material was applied to the ceiling, the sound pressure level decreased throughout the space. In Cases 3, 4, and 5, the sound pressure level of the space immediately below the emergency broadcasting speaker was affected more by the direct sound than by the reflected sound. appeared higher than noise when the evacuation safety area was divided into a machine room or a part of the electrical room will be directly affected by existing studies (10, 11) that measured machine room noise characteristics, suggesting that the noise of machinery was distributed in the range of 65 dBA to 105 dBA and had a level of 75 dBA or higher in many cases. Thus, to set a partial space for the machine room or electrical room as an evacuation safety zone, a plan to insulate the noise from the machine room transmitted to the safe evacuation zone space is required.

The background noise increased as the area where the speech transmission index was "Good" decreased. This means that speech transmission in fire safety zones can be improved by improving speaker placement for emergency broadcasting, in addition to using sound-absorbing materials and lowering the background noise level. If sound-absorbing materials are applied to the fire safety zones and the arrangement of emergency broadcasting speakers is improved, the average spatial value of the STI increases. In addition, a plan for clearly delivering emergency broadcast messages is required in all spaces of the fire safety zone.

4. RESULTS AND DISCUSSIONS

To ensure the safe evacuation of the residents of the high-rise building, it is mandatory to install fire safety zones in Korea. In fire safety zones, alarm and communication facilities that enable emergency contact with management offices and disaster-prevention centres, as well as emergency broadcasting facilities, must be installed. Fire safety zones generally consist of non-combustible materials or are set in certain areas of machine rooms, making it difficult to have smooth vocal conversations and clear emergency broadcasts due to severe echoes or noises from various mechanical devices. In this study, the acoustic room characteristics of fire safety zones were predicted.

By predicting the room acoustic characteristics and speech intelligibility (speech transmission index, STI) of emergency broadcast messages, it was confirmed that the reverberation time was substantially long because of the use of non-combustible materials as interior finishing materials. The broadcasting sound generated by the emergency broadcasting speaker was delivered at a sufficient volume; however, as a result of the evaluation of the speech intelligibility of the emergency broadcasting sound, the STI was evaluated as “Poor–Bad”, making it difficult to accurately understand the actual broadcast message.

In addition, as the background noise level increased, the distribution of the STI decreased, and when the background noise was louder than 70 dBA, the distribution of STI was evaluated as “Poor–Bad” with a rating of 0.3 or less.

To deliver emergency broadcast messages in fire safety zones, it is necessary to reduce reverberation; therefore, it is necessary to replace non-combustible finishing materials with inorganic sound-absorbing materials. The simulation results indicated that the reverberation time was shortened by approximately 70% on average when inorganic sound-absorbing materials were used. It was confirmed that the emergency broadcasting equipment needs to be improved along with the reverberation time to deliver a clear emergency broadcasting message. Thus, a system is needed that always transmits an emergency broadcasting message at a level higher than an appropriate level than the background noise level. Moreover, a plan for improving the arrangement of emergency broadcasting speakers is required. To improve emergency broadcasting facilities, it is necessary to have an STI above a certain level at all locations where emergency broadcasting facilities are installed. Through the establishment of standards for the STI of emergency broadcasting facilities, the shape of the area of interest and finishing materials can be selected from the design stage of various facilities, and appropriate emergency broadcasting facilities can be designed and constructed with a comprehensive consideration of emergency broadcasting facilities.

In this study, improvements in the ceiling sound absorption characteristics and background noise levels were set as variables and compared. A study on the Lombard Effect, in which the background noise increases as the number of evacuees increases in the actual evacuation safety area, and improvement plans should be established.

REFERENCES

[1] Special Act on Disaster Management of High-rise and Underground-Linked Buildings, Fire Safety Code on High-rise Buildings, Korea Ministry of Government Legislation, 2019.

[2] National Fire Safety Code 604 – Fire Safety Code on High-rise Buildings, Korea Ministry of Government Legislation, 2017.

[3] H. Brumm and S. A. Zollinger, "The Evolution of the Lombard Effect: 100 years of Psychoacoustic Research", *Behavior* 148, pp. 1173-1198, 2011.

[4] J. H. Jeong, "Alarm Sound Propagation Characteristics of Gas Extinguishing System Installed in Computer Server Room", *J. Korean Soc. Hazard Mitig*. Vol. 20, No. 4, pp. 145-152, 2020.

[5] IEC 60286-16 Sound System Equipment – Part 16: Objective Rating of Speech Intelligibility by Speech Transmission Index, International Electrotechinical Commission, 2011.