Chapter 7

Effects of Platform Screen Doors on Sound Fields in Underground Stations

Yoshiharu Soeta and Yong Hee Kim

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/64627

Abstract

This chapter investigates the acoustic effects of platform screen doors (PSDs) in underground stations using computer simulation and scale model testing. The dimensions of underground stations with island and side platforms were determined based on a field survey. Ray-tracing-based computer models and 1/25 scaled-down physical models of these underground stations were used to simulate their sound field characteristics. In the experiments, five types of PSDs were tested: mobile closed full-height (MCFH), mobile open full-height (MOFH), mobile half-height (MHH), fixed half-height (FHH) and fixed barrier (FB) doors. Four acoustic parameters, namely, speech intelligibility, sound pressure level, reverberation time and the inter-aural cross-correlation coefficient were used to understand the sound field characteristics from the sound source of public address announcements. It was found that speech intelligibility and the sound pressure level were increased by most types of PSDs apart from the MCFH. The MOFH showed the highest levels of speech intelligibility and spatial diffusivity. In addition, the noise reduction effects of PSDs for train noise were discussed. PSDs on side platforms showed higher noise reduction performances than PSDs on island platforms. The specific noise reduction levels for the MOFH type were 4.3 dB on island platforms and 5.0 dB on side platforms.

Keywords: platform screen door, underground station, computer simulation, scale model testing, speech intelligibility

1. Introduction

Noise in train stations can annoy the passengers, reduce the speech intelligibility on public address systems in the stations [1–3] and also pose the risk of causing noise-induced hearing loss in passengers, transit workers and operators [4–6]. The control of noise in train stations is thus important for the comfort, convenience and safety of passengers, transit workers and station staff. However, relatively few acoustical treatments are conducted in most train stations.

The architectural conditions of train stations are diverse, and their sound fields differ according to the station type. The effects of the location, i.e. whether the station is located aboveground or underground, and the platform style, which can be side (two platforms at the side and the rail tracks at the centre) or island (one platform at the centre and rail tracks on both sides), on the train noise in stations have been investigated recently [7]. The results show that the noise level in underground stations is 6.4 dB higher than that in aboveground stations, and that noise level in underground stations with island platforms, which are the most widely used types of stations in Japan for economic reasons, is higher than those with side platforms. This indicates that acoustic treatments are necessary for underground stations with island platforms.

Recently, platform screen doors (PSDs) have been widely applied in the platform areas in train stations for passenger safety in Asian and European metro systems [8, 9]. PSDs help to prevent falls from the platform onto the track area, reduce the risk of accidents being caused by service trains passing through stations at high speeds and improve the climate control, e.g. heating, ventilation and air conditioning, within the station. Railway companies in Japan are also encouraged to install PSDs for safety reasons. There are approximately 9500 train stations in Japan and approximately 4% of these stations have installed PSDs. More than 200 accidents leading to injury or death occurred in these stations in 2008. Over a 2-year period from 2008 to 2010, 61 train stations installed PSDs. The number of accidents that occurred in stations subsequently decreased by approximately 10%.

PSDs have a positive impact on safety in train stations, and they also have an effect on the train noise in stations because they are a type of wall that blocks the noise generated by trains. Some studies have reported that the acoustic environments in underground stations were improved by isolating the train noises [7, 10–14]. The strongest effect of the use of PSDs is the reduction of the train noise level. Reported noise reduction levels produced by the presence of PSDs in underground stations ranged from 9 to 18 dB in field measurements [10–14]. In the case of underground stations in the Seoul Metro, in South Korea, the equivalent sound pressure levels of the train noise from the arrival to departure process in stations with PSDs were approximately 71 dB(A), whereas those in stations without PSDs ranged from approximately 78 to 82 dB(A) [10]. The differences between the *in situ* measured sound pressure levels inside and outside PSDs were reported to range from 16 to 18 dB(A) [11]. In addition, reinforcement of early reflections for sounds from the public address (PA) systems was also found [9].

The changes in the sound field characteristics caused by the PSDs have rarely been studied. In particular, the contributions of PSDs to the improvement of speech intelligibility are yet not known. Also, the noise reduction effects of PSDs in a previous study [14] were derived from field measurements in different train stations because it was impossible to change the PSDs, after they have been installed. Different train stations have different acoustic characteristics, including volume, reverberation and background noise. Also, many different types of trains, which have different noise source characteristics, run through train stations that were measured, and thus it was impossible to eliminate the effects of the different noise sources in the field measurements. Therefore, the noise reduction performances of different PSDs can be predicted more accurately through a simulation approach using reliable acoustic models and different platform styles.

This study therefore investigated changes in the sound field characteristics including the noise reduction effects for different types of PSDs using computer simulations and acoustic scale modelling. It was hypothesized that the speech intelligibility and noise reduction performance levels would be improved by the presence of PSDs, depending on the type of platform shape.

2. Methods

2.1. Target underground stations

The architectural conditions of train stations are diverse, and their sound fields differ according to the station type. In terms of location, an aboveground station covered only by a roof is similar to a free sound field, while a completely covered underground station is a reverberant sound field [15]. To focus on the effects of reflections from the PSDs, the walls and the ceilings, only underground stations were simulated in this study.

In terms of platform style, stations can be principally divided into side (two platforms at the side and rail tracks at the centre) and island (one platform at the centre and rail tracks on the sides) platforms. In underground stations, the train runs down the centre of a station with side platforms, while it runs against the lateral wall of a station with an island platform. These different architectural elements can also change the characteristics of the sound fields.

Figure 1 shows the two simplified underground stations with island and side platforms that were selected for the study. Full details of the target stations, including their acoustic fitting to real stations, have been described in previous studies [7, 14, 16]. The platform length for both stations was 150 m, with a corridor height of 3 m. The width of a single track was 3.6 m. The distance between the track and the platform floors was 1.1 m. The maximum station height for both stations was 5.3 m at the position of the middle of the track. The maximum station width was 14.8 m for the island platform-type station, and 17.2 m for the side platform-type station. The cross-sectional area was 61 m^2 for the island platform-type station, and 68.2 m^2 for the side platform-type station. Both stations were simulated without either passengers or background noise.

2.2. Platform screen doors

Figure 2 shows the five types of PSDs that were used in this study: three mobile (MCFH: closed full-height, MOFH: open full-height, MHH: half-height) and two fixed (FHH: half-height, FB: barrier) types of PSD. The PSD dimensions were determined based on practical designs. The doors and the lower walls of the PSDs were made from tempered glass. The upper walls of the PSDs were made from sheet metal.

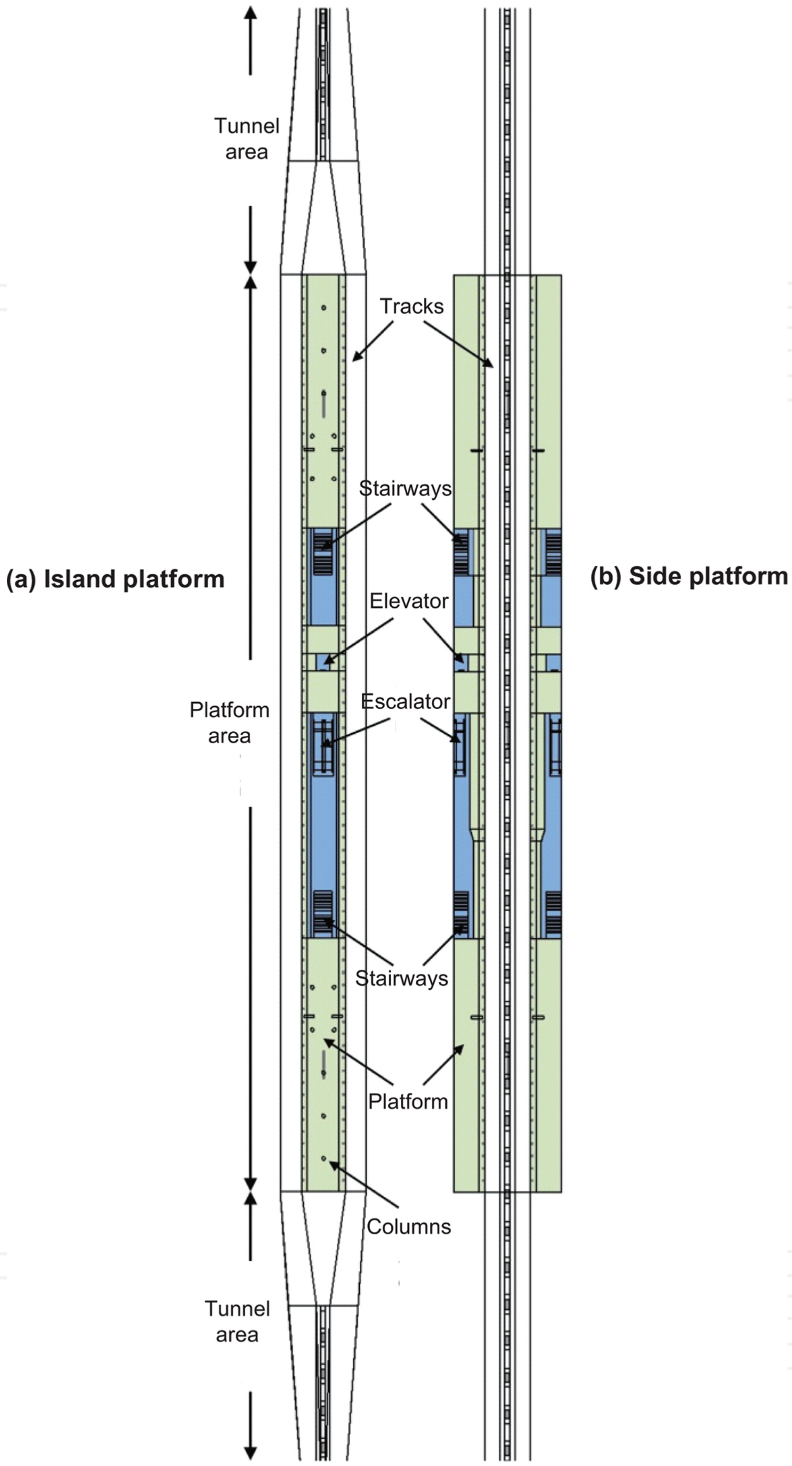

Figure 1. Floor plan of the target underground stations with (a) island and (b) side platforms.

2.3. Simulation models using the ray-tracing method

Ray-tracing software (Odeon 11.23) was used to derive the acoustic parameters and the binaural impulse responses. As shown in **Figure 3**, a total of 12 cases were simulated for the various PSD configurations, including the no-PSDs condition (NSD). For the simulation parameters, the transition order was 1 with 120,000 rays. The environmental conditions were 20°C and 50% relative humidity (RH).

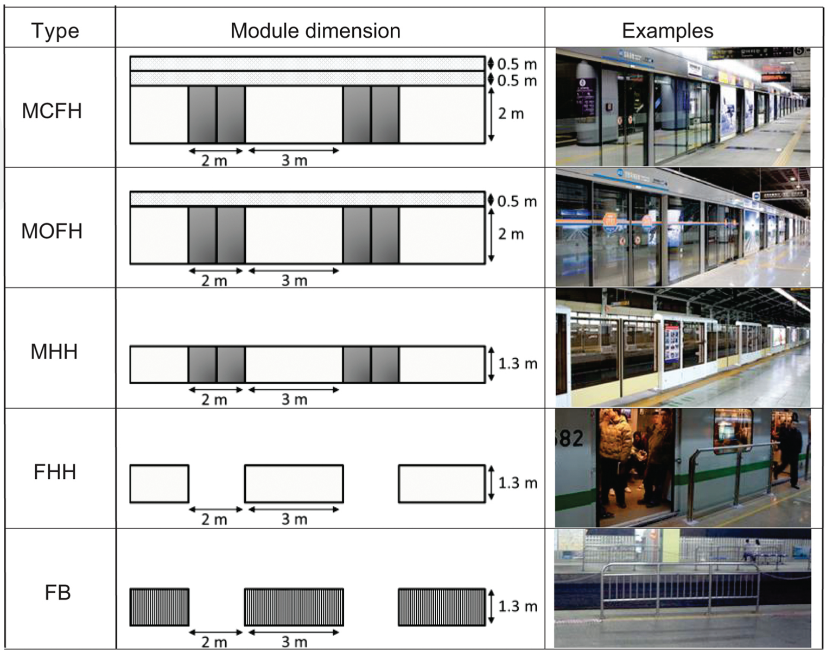

Figure 2. Modules of the five types of PSDs with their dimensions.

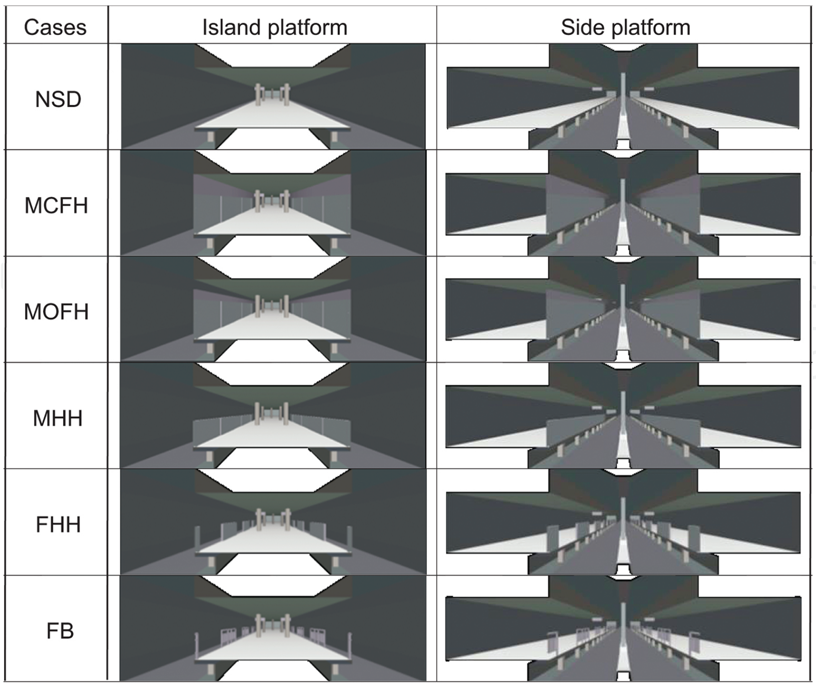

Figure 3. Simulation configurations according to the types of PSDs.

2.4. Physical models on 1/25 scale

A 1/25 scale model station with an island platform was built to validate the computer simulation results. The main body of the scale model was made from 9-mm-thick medium-density fibreboard with a varnish coating. The PSDs were made from 1-mm-thick Foamex plastic board (a type of polyvinyl chloride plastic). **Figure 4** shows the model testing configurations for the different types of PSDs.

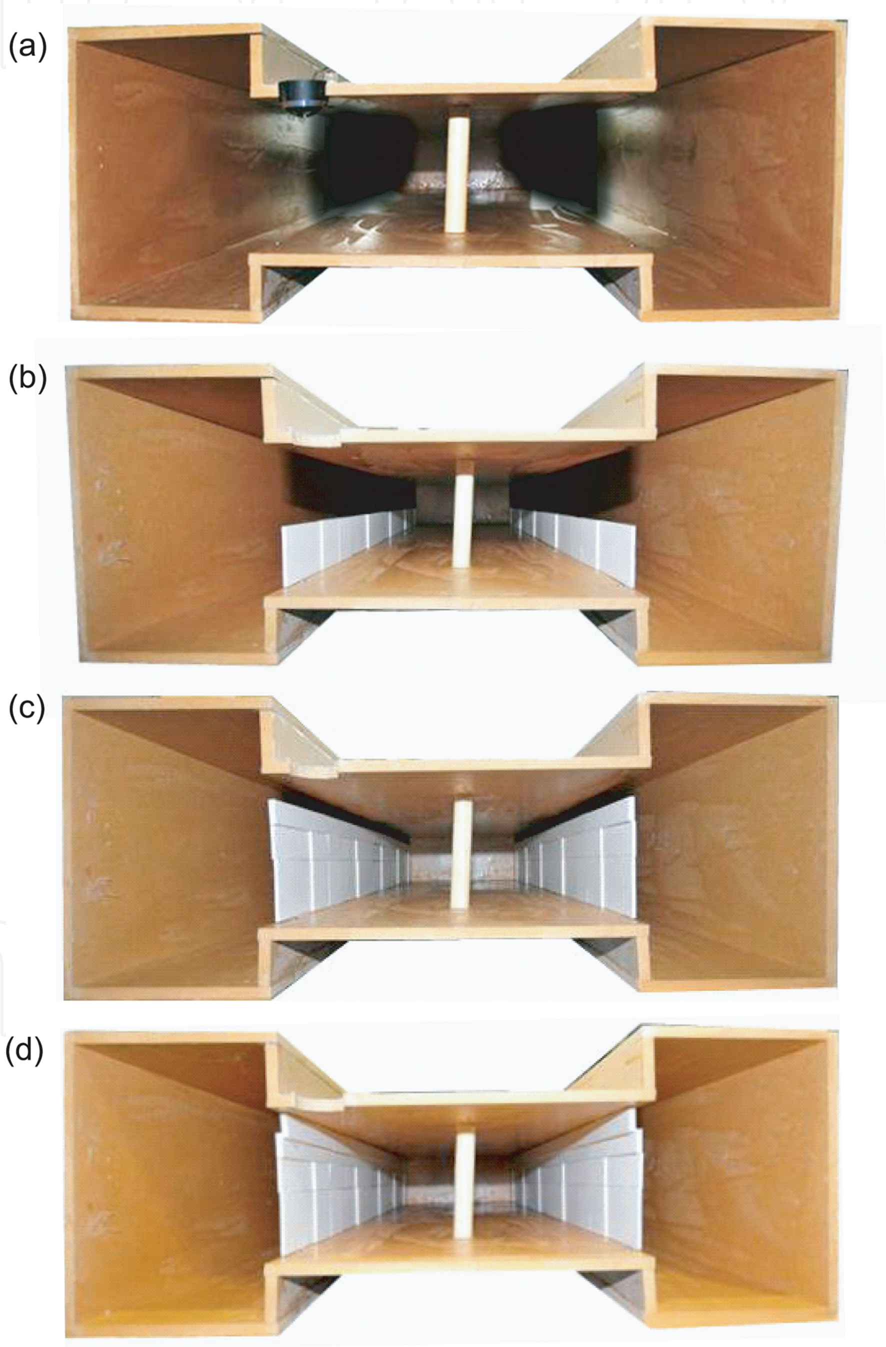

Figure 4. Section of the scale model stations with PSDs (a) NSD, (b) MCFH, (c) MOFH and (d) MHH.

2.5. Source and receiver position

In this study, two measurement configurations were used for the investigations. **Figure 5** shows the source and receiver positions for Configuration 1 in both the simulation and scale models for evaluation of the sound field characteristics to determine the speech intelligibility of PA sounds. A sound source at a height of 2.8 m (0.112 m in the scale model) was located 22.5 m (0.9 m in the scale model) away from the rear wall of the platform in the longitudinal direction. In total, 14 receivers were placed at a height of 1.6 m (0.064 m in scale model) on either side of the sound source in the longitudinal direction. The distance between the receivers was 2.5 m (0.1 m in the scale model).

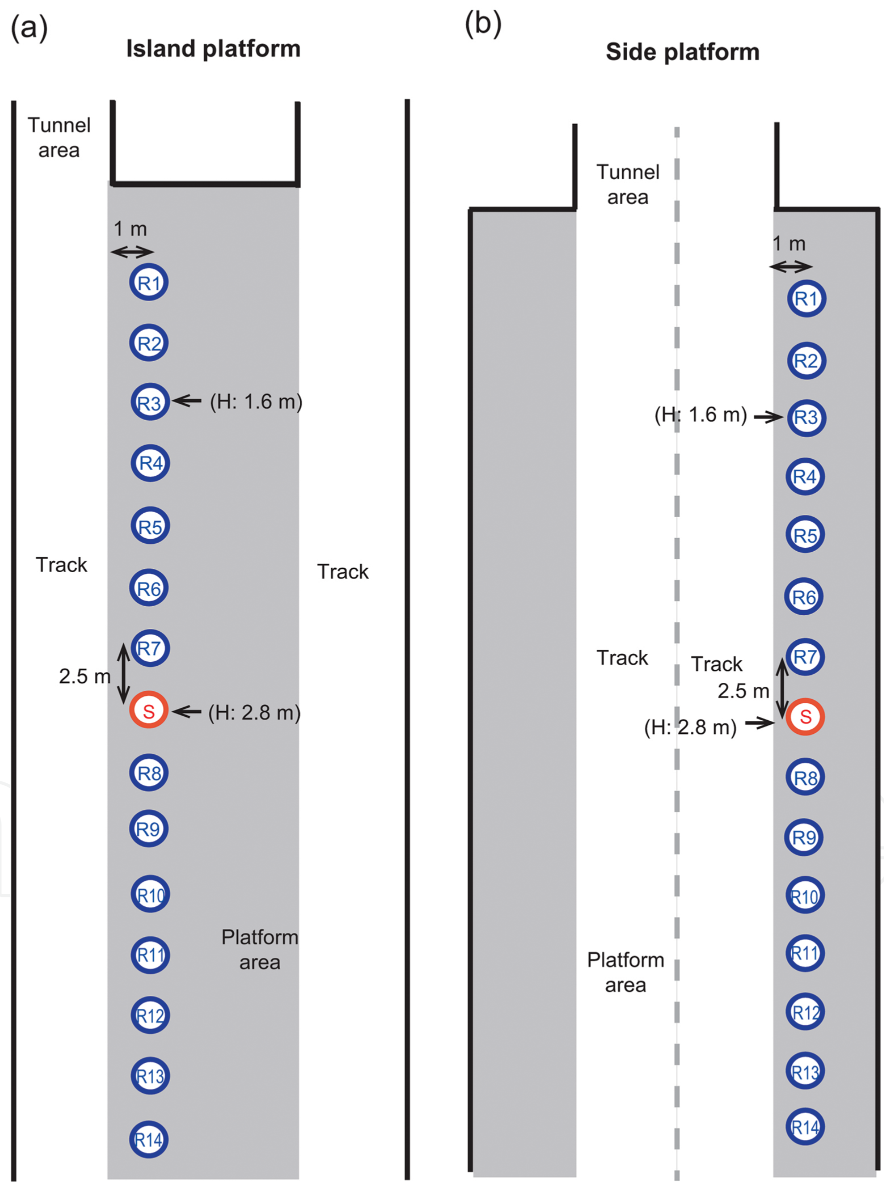

Figure 5. Source and receiver positions used to evaluate speech intelligibility of PA sounds (Configuration 1). (a) Island and (b) side platforms.

Figure 6 shows source and receiver positions of Configuration 2 for evaluation of the noise level of an approaching train to determine the noise reduction effects of the PSDs. Nine sound sources were located at a height of 0.5 m (0.02 m in the scale model) along the track with spacing of 15 m between them. Sound sources S1 to S3 were located inside the tunnel area. At the S1, S4 and S7 source positions, additional source heights of 2.3 m (0.092 m in the scale model) and 4.1 m (0.164 m in the scale model) were considered. Thirteen receivers were located at a height of 1.6 m with spacing of 5 m (0.2 m in the scale model) between them, in the same manner as the above configuration for sound field evaluation. R1 to R8 are classified as the front receivers, while R9 to R13 are classified as middle receivers.

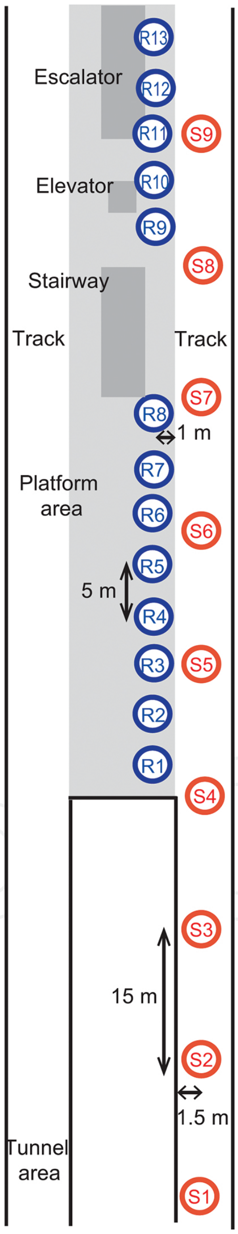

Figure 6. Source and receiver positions used to evaluate the noise level of an approaching train (Configuration 2).

http://dx.doi.org/10.5772/64627

2.6. Acoustic parameters

Four acoustic parameters, namely, the speech transmission index (STI), the sound pressure level (SPL), the reverberation time (RT, T30) and the inter-aural cross-correlation coefficient (IACC) [17, 18], were used to quantify the sound field characteristics using Configuration 1.

The STI is an objective measure of speech transmission quality. The STI measures certain physical characteristics of acoustic transmission in a room and is affected by the speech level, the frequency response of the room, the background noise level, the reverberation and other parameters. The STI ranges from 0 to 1. An STI of 1 indicates perfectly intelligible speech conditions. In general, the intelligibility rating is determined according to the STI value: 'excellent' for an STI of more than 0.75, 'good' for an STI of 0.6 to 0.75, 'fair' for an STI of 0.45 to 0.6, 'poor' for an STI of 0.3 to 0.45 and 'bad' for an STI of less than 0.3.

The SPL is a logarithmic measure of the sound strength at a specific position. To calculate the SPL, a reference value of 20 μPa and an A-weighted and octave band filters were commonly used in consideration of the human hearing threshold. Therefore, an SPL of 0 dB(A) indicates the minimum audible limit. The frequency range usually covers the range from at least 125 to 4000 Hz in octave bands.

The RT (T30) is defined as the time required for the SPL to decrease by 60 dB in a room, at a rate of decay that is given by a linear least-squares regression of the measured decay curve from a level 5 dB below the initial level to 35 dB below that level. The decay curve was obtained by reverse-time integration of the squared impulse response in each octave band. A higher RT value indicates a higher level of reverberation. To derive single number ratings, the SPL and the RT were averaged in the 500 and 1000 Hz octave bands.

The cross-correlation function between the signals obtained from the left and right ears is called the inter-aural cross-correlation function (IACF). The IACC is defined as the maximum absolute value of the IACF within the maximum possible inter-aural delay range for humans of 1 ms. The IACC correlates well with the subjective quality of 'spatial impression'. The spatial impression can be divided into two subclasses: Subclass 1 covers the broadening of the source, i.e. the apparent source width (ASW); Subclass 2 covers the state of diffusion of the reverberant sound field, i.e. the listener envelopment (LEV). To calculate the IACC, an A-weighted filter was included without spectral filtering. The IACC value ranges from 0 to 1. An IACC of 1 indicates that the signals from the left and right ears are identical, whereas an IACC of 0 indicates that they have no correlation at all. Usually, a lower IACC value indicates more diffused sound fields.

Also, the noise reduction level (NRL) overall bands was calculated as the SPL with the PSDs subtracted from the SPL without the PSDs to evaluate the noise level of an approaching train using Configuration 2.

2.7. Measurement setup in the scale model

Because the scale factor of 1/25 was used, a limited frequency range of up to 3840 Hz was measured through a tweeter loudspeaker (Clarion dome tweeter SRH294) and an analogue-to-digital/digital-to-analogue (AD/DA) converter (Roland Cakewalk UA-101) with a sampling rate of 192 kHz. Therefore, the STI in the scale model test was averaged from 500 to 1000 Hz. In addition, the IACC was not derived in the scale model test because of the use of a monaural microphone (B&K 1/4-inch microphone Type 4939-A-011, and B&K NEXUS conditioning amplifier Type 2690). During the measurements, the air temperature and the RH ranged from 21 to 26°C and 61 to 65%, respectively. The air absorption was corrected to calculate the RT as a real-scale condition at 20°C and 50% RH [19].

3. Results

3.1. Sound field characteristics by PSDs

The acoustic parameters were averaged for a single sound source and 14 receivers using Configuration 1. The parameters were expressed as relative values with reference to the NSD condition without any PSDs. Therefore, as an example, ΔSPL indicates the SPL without the PSDs subtracted from the SPL in each case.

3.1.1. Speech transmission index

Figure 7(a) shows the results for the STI values that were changed by the presence of the different types of PSDs from computer simulations and scale model testing. Apart from the case of the MCFH in the computer simulation, the STI was increased by the PSDs. In the MOFH case, the STI was maximally increased in both stations, by 3% in the island platform type and by 6% in the side platform type. The MHH cases showed similar STI increments to the MOFH cases. Because the fully closed cases (MCFH) showed the worst performance, it was found that the lower walls of the PSDs were important for improved speech intelligibility. The scale model results also confirmed the effectiveness of the PSDs in increasing the STI. However, the MCFH in the scale model showed increased STI values because the absorption properties of the model PSDs were slightly higher (0.07 in the mid-frequency range) than those of the real PSDs (0.03 in the mid-frequency range, tempered glass pane). In addition, the PSDs on the side platforms were more effective in increasing the STI than those on the island platforms, although the STI of the NSD case in the side platform-type station was 0.01 higher than that in the island platform-type station.

3.1.2. Sound pressure level

Changes in the SPL for the various types of PSDs from the computer simulations and scale model tests are shown in **Figure 7(b)**. In the computer simulations, the MCFH cases showed the highest increases in SPL of more than 3 dB for both island and side platforms. The MOFH cases showed relatively high SPL reinforcements. This tendency was also confirmed by the scale model results, although the SPL in the scale model was increased by approximately 1 dB because of the different absorption properties of the PSDs. However, the other cases showed only small changes in the SPL. In fact, the SPL was reduced in the FB case in particular.

http://dx.doi.org/10.5772/64627

Therefore, it was found that the upper walls of the PSDs were important for reinforcement of the SPL. Similar to the results for the STI, the side platform-type station was more effective in increasing the SPL than the island platform type.

3.1.3. Reverberation time

Figure 7(c) shows the results for the RT difference for the various types of PSDs from the computer simulations and scale model testing. In the computer simulations, the two full-height cases (MCFH and MOFH) showed greater RT reductions due to the PSDs in both the island and side platform cases. It seems that the reduction of the effective room volume by the PSDs was the main cause of the reduced RT. The MOFH cases in particular showed similar results to the MCFH cases, despite their upper walls being open. The scale model results confirmed

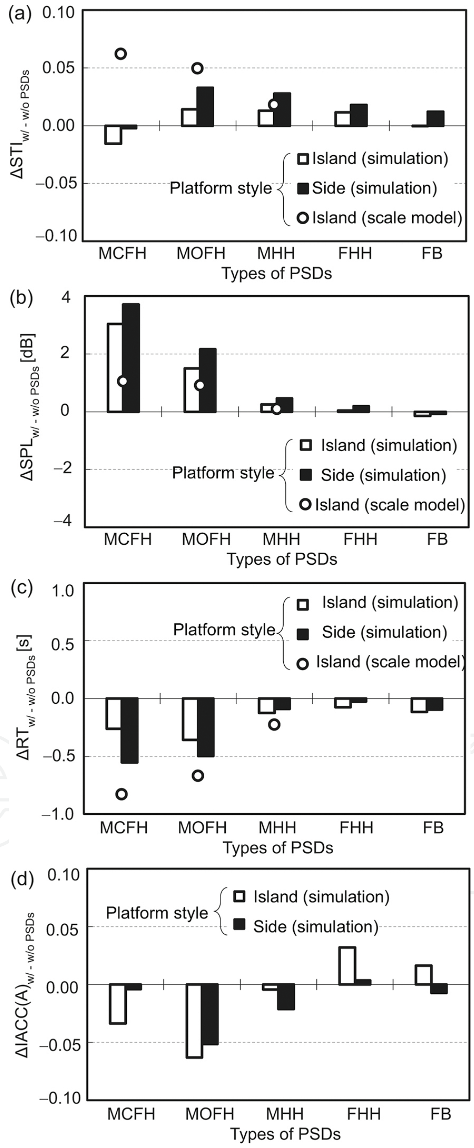

Figure 7. Differences in acoustical parameters between NSD and the other cases with PSDs. (a) STI, (b) SPL, (c) RT and (d) IACC.

that the RT was reduced by the PSDs. Also, the side platforms only showed greater RT reductions than the island platforms in the MCFH and MOFH cases. The FB also showed a reduction in RT when compared with the results of the SPL.

3.1.4. Inter-aural cross-correlation coefficient

The differences in the IACC for the various types of PSDs are plotted in **Figure 7(d)**. The MOFH showed the greatest IACC reduction for both station types. It seems that the coupling effects of the upper opening in the MOFH promoted the diffusion of reflections. The MCFH in the island platform type and the MHH in the side platform type also showed a reduction in the IACC values. However, the IACC increased in the FHH and FB cases on island platforms.

3.2. Noise reduction effects of PSDs

The NRLs were averaged from the nine sound sources and 13 receivers of Configuration 2. **Figure 8** shows the NRL results for the PSDs in the island and side platform configurations. The MOFH showed the highest NRL values for both island and side platforms. For the front receivers (R1 to R8), the NRL produced by the MOFH was 4.3 dB on the island platform and

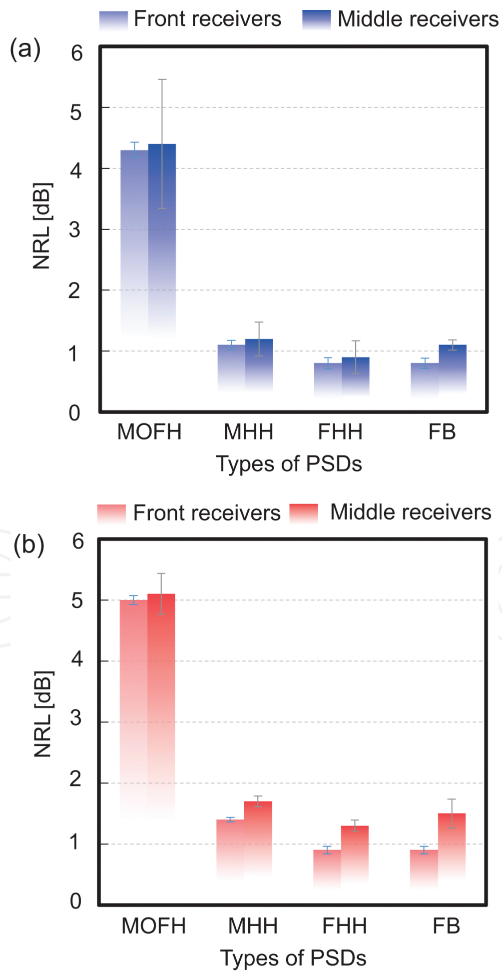

Figure 8. NRL values for each of the types of PSDs for (a) island and (b) side platforms.

5.0 dB on the side platform. These results show good agreement with those of the previous study that used field measurements [14]. The NRL produced by the MHH was 1.1 dB on the island platform and 1.4 dB on the side platform. The NRL values produced by the FHH and the FB were 0.8 dB on the island platform and 0.9 dB on the side platform. Therefore, the side platform-type stations showed higher NRL values than the island platform-type stations. This difference seems to be caused by the different boundary conditions of the platform sound fields when surrounded by the PSDs and the lateral walls.

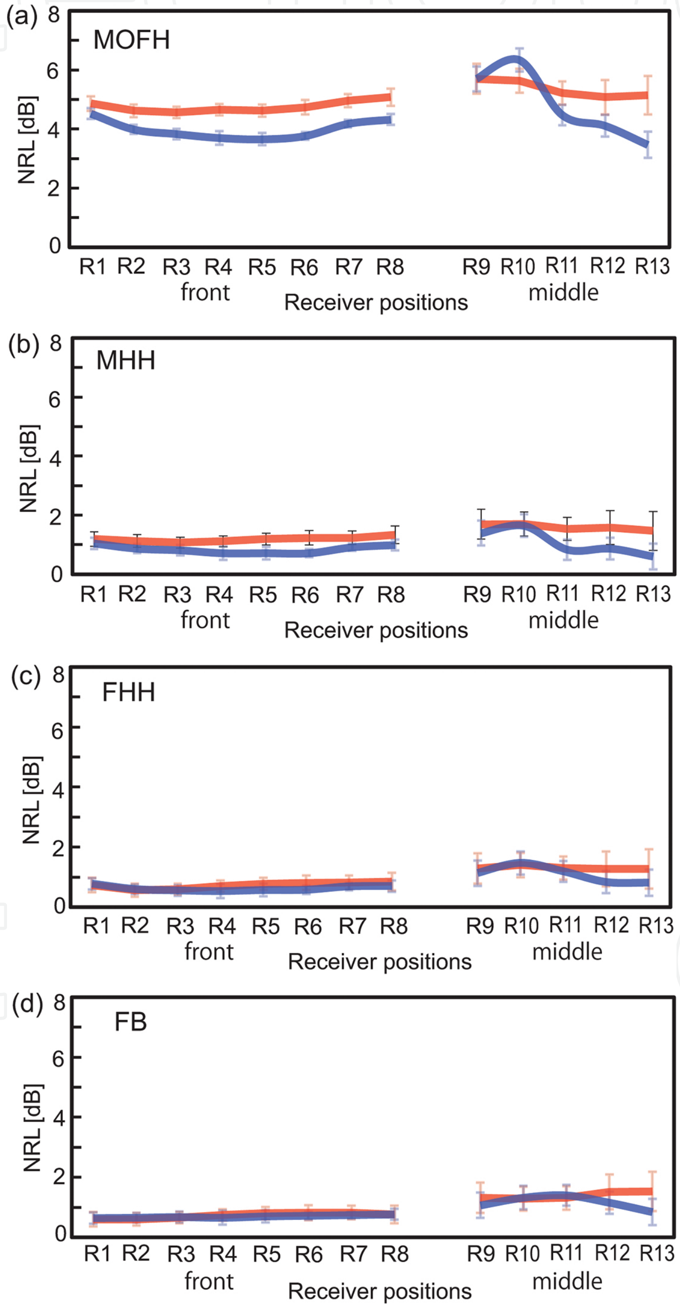

Figure 9. Variation of NRL values with receiver positions for (a) MOFH, (b) MHH, (c) FHH and (d) FB (blue line: island platform: red line: side platform).

In contrast, the middle receivers (R9 to R13) showed NRL values of 0.1–0.6 that were slightly higher than those of the front receivers. Smaller PSD profiles produced larger NRL differences between the front and middle receivers. The NRL seems to be affected by the presence of more diffusive interior elements in the middle platform area than in the front platform area.

3.2.1. Effects of receiver positions

To assess the effects of the receiver positions, the NRL distributions were plotted as shown in **Figure 9**. In the frontal platform area, stable NRL values were observed, with slight decay at the R4 and R5 positions. However, in the central platform area, dramatic changes in the NRL were observed. In particular, the R10 position beside the elevator shaft showed peak NRL values. The island platforms showed more fluctuating NRL values than the side platforms. These fluctuations seem to be caused by the opposite PSD walls in the island platform-type station, whereas the side platform-type station has only one PSD wall.

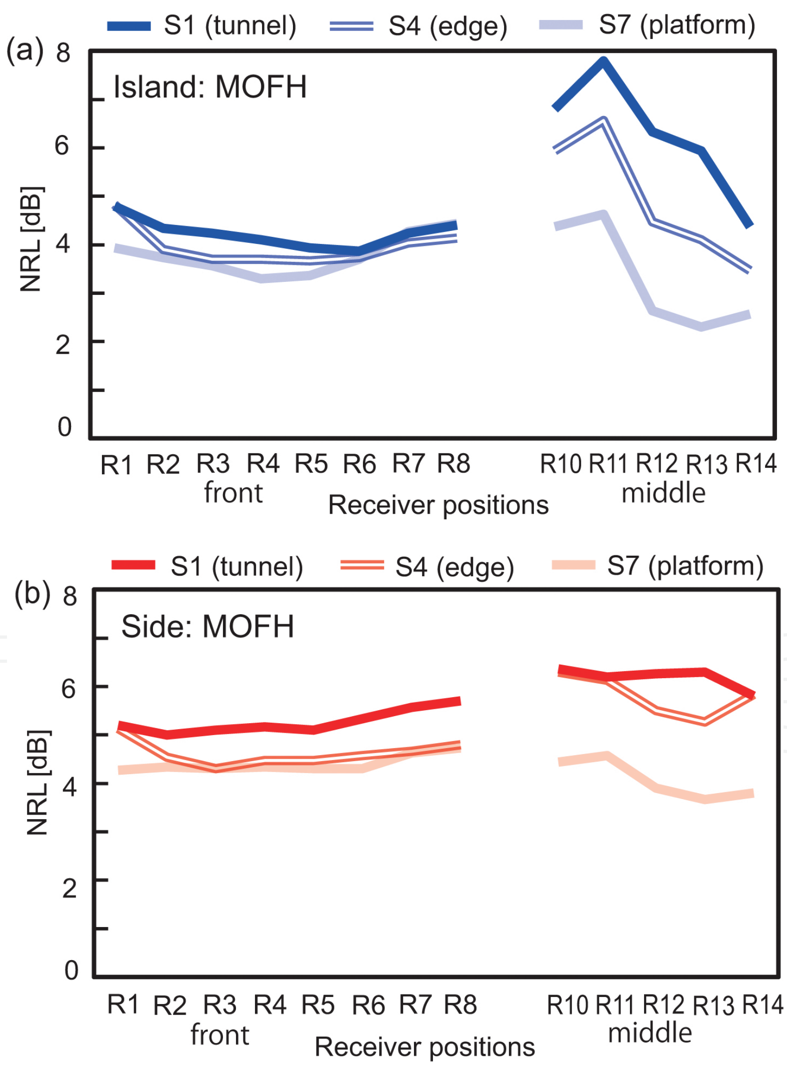

Figure 10. Variation NRL values according to source positions in case of MOFH for (a) side and (b) island platforms.

3.2.2. Effects of source positions and heights

Figure 10 shows the results for the NRL values according to the source positions in the MOFH case. Each NRL value for each receiver position was averaged for S1, S4 and S7. The MOFH showed higher NRL values for sound sources in the tunnel area than for the other source positions. This means that the PSDs are helpful in reducing relatively low level train noises. Particularly, large fluctuations in the NRL were observed in the middle platform area of the island platforms. Side platforms tend to show more relatively stable NRL values than island platforms.

Figure 11 shows the results for the NRL values based on the source heights in the MOFH case. Each of the NRL values for each receiver position were averaged for heights of 0.5, 2.3 and 4.1 m and were also averaged for S1, S4 and S7. On the island platform, the frontal receivers showed stable NRL values with respect to source height variation. However, the middle receivers on the island platform and the frontal receivers on the side platforms showed relatively large variation in their NRL values for different source heights. Lower sources tended to show higher NRL values.

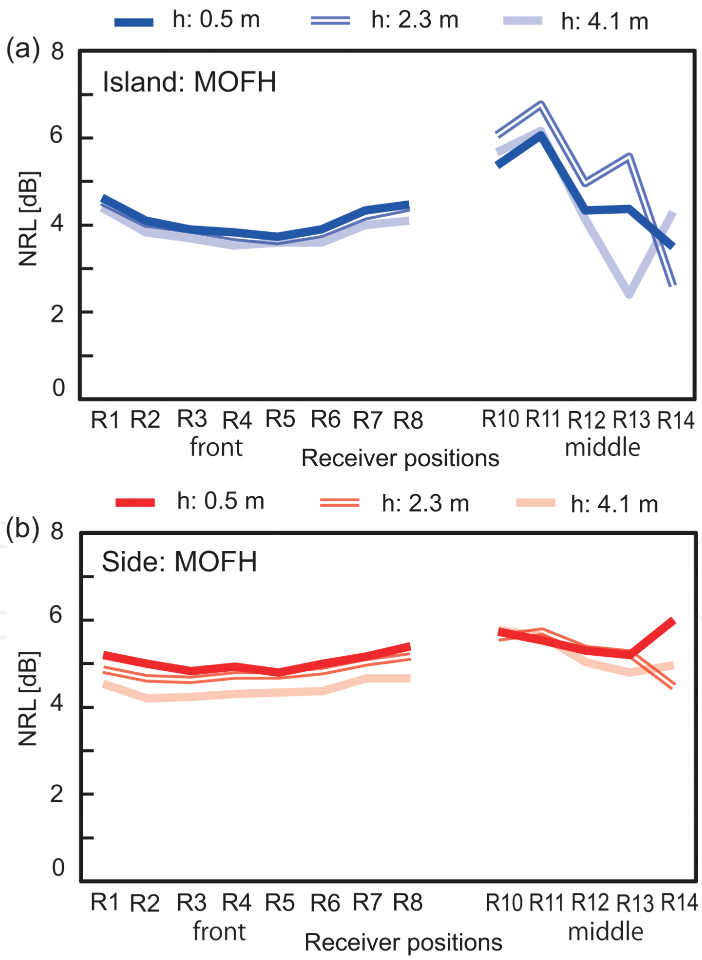

Figure 11. Variation of NRL values with source height in the MOFH case for (a) side and (b) island platforms.

4. Concluding remarks

In this study, the effects of PSDs on the sound field characteristics of underground stations and their noise reduction effects were investigated using both computer simulations and scale model testing. As a result, it was found that most types of PSDs were effective in increasing the STI with a higher SPL and reduced RT, apart from the MCFH type. Specifically, the MOFH was found to be the most effective type of PSD in terms of maximizing the STI with the lowest IACC. In addition, the noise reduction levels of these PSDs for train noise were derived for each type of PSD. PSDs on side platforms generally showed higher noise reduction performances than PSD on island platforms. In particular, the noise reduction level demonstrated by the MOFH type was 4.3 dB on island platforms and 5.0 dB on side platforms. Middle platform areas showed more unstable NRL values than frontal platform areas because they contained diffusive interior elements such as elevators or stairways. In conclusion, PSDs are helpful in reinforcing speech intelligibility and loudness for public address announcements while reducing train noise. As a potential future approach, the presence of background noise levels and the absorption effects of the passengers could also be considered to provide more realistic simulation results.

Acknowledgements

This work was supported by Grants-in-Aid for Scientific Research (B) (Grant No. 15H02771) and for Young Scientists (A) (Grant No. 23686086) from the Japan Society for the Promotion of Science.

Author details

Yoshiharu Soeta[1] and Yong Hee Kim[2*]

*Address all correspondence to: yhkim@kcl.re.kr

1 National Institute of Advanced Industrial Science and Technology (AIST), Ikeda, Osaka, Japan

2 Korea Conformity Laboratories (KCL), Ochang, Cheongju, Chungbuk, Korea

References

[1] Bhattachaya SK. Assessment of noise environment in a major railway station in India. Industrial Health. 1994; 32: 187–192.

[2] Endoh H, Suzuki H, Izumi Y, Hio Y. Appropriate sound level of broadcasting on station platforms under noisy environment. Railway Technical Research Institute Report. 2007; 21: 41–46 [in Japanese].

[3] Isumi Y, Fujii K, Iwase T. An investigation into the actual condition and subjective evaluation test of acoustical environment in railway station. Journal of Environmental Engineering. 2011; 76: 115–124 [in Japanese].

[4] Cohen A, Anticaglia J, Jones H. Sociocusis hearing loss from non-occupational noise exposure. Sound Vibration. 1970; 4: 12–20.

[5] Chang HC, Hermann ER. Acoustical study of a rapid train system. American Industrial Hygiene Association Journal. 1974; 35: 640–653.

[6] Johanning E, Wilder DG, Landrigan PJ, Pope MH. Whole-body vibration exposure in subway cars and review of adverse health effect. Journal of Occupational and Environmental Medicine. 1991; 33: 605–612.

[7] Shimokura R, Soeta Y. Evaluation of speech intelligibility of sound fields in underground stations. Acoustical Science and Technology. 2011; 32: 73–75.

[8] Kim SW, Seong KC, Kang BK. The study of introducing the screen door in subway station. Journal of Korea Institute of Healthcare Architecture. 2004; 10: 51–58 [in Korean].

[9] Oldfield A, Babic F. Acoustic design of transit stations. Journal of the Acoustical Society of America. 2012; 132: 2085.

[10] Lee MJ, Oh HW, Kim MJ. Measurement and analysis on the noise by train cars at platform of subway station. Journal of the Korean Society of Living Environmental System. 2009; 16: 126–133 [in Korean].

[11] Kim JC, Jeon SW, Koo DH. Analysis of noise reduction effect for platform screen door in the subway. Proceedings of Korean Society for Precision Engineering; 2009: 1067–1068 [in Korean].

[12] Nam JH, Park KS, Son WT, Ko JL, Shin JW. A study on the indoor noise reduction by installation of platform screen doors in a subway. Proceedings of the Society of Air-conditioning and Refrigerating Engineers of Korea; 2010: 1130–1135 [in Korean].

[13] Lee CM, Jung JG, Jung JS. Investigation and evaluation of noise level of the Busan subway. Journal of Korean Society of Environmental Engineers. 2011; 33: 243–250 [in Korean].

[14] Soeta Y, Shimokura R. Change of acoustic characteristics caused by platform screen doors in train stations. Applied Acoustics. 2012; 73: 535–542.

[15] Shimokura R, Soeta Y. Characteristics of train noise in ground and underground stations with side and island platforms. Journal of Sound and Vibration. 2011; 330: 1621–1633.

[16] Kim YH, Soeta Y. Design of diffusive surfaces for improving sound quality of underground stations. Proceeding of the International Symposium on Room Acoustics (ISRA), Toronto; 2013: P111.

[17] IEC 60268-16 (2003). Sound system equipment—Part 16: Objective rating of speech intelligibility by speech transmission index.

[18] ISO 3382-1 (2009). Acoustics–Measurement of room acoustic parameters—Part 1: Performance spaces.

[19] ISO 9613-1 (1993). Acoustics—Attenuation of sound during propagation outdoors—Part 1: Calculation of the absorption of sound by the atmosphere.