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Airborne Sound Insulation Performance of Window and Indoor Noise Level in the Balcony Expanded Apartments

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ABSTRACT

Purpose: The balcony in the apartment is important space not only as a fire escape but also as a buffer for heat and sound insulation. However, with the legalization of balcony expansion for residential apartments in Korea in 2006, many households have eliminated the balcony space altogether to increase the inner space, often without sufficient consideration for the effects on the indoor environment. This study examined the sound insulation performance of exterior-facing windows in enclosed balconies and the changes in the indoor acoustic environment due to expansion to provide a basis for appropriate balcony expansion. The apartments for the field test were chosen where two balcony types can be compared, and the sound insulation performance for the eighteen balcony windows was measured. The windows installed were typical double window with thickness 16 mm or 22 mm. Measurements of the weighted standard sound pressure level difference showed a decrease of about 3 dB in sound insulation performance due to expansion. For common exterior noise levels of 70-85 dB(A), the indoor noise level can exceed 45 dB(A), the limit level regulated in Korea. However, it was found that the sound insulation performance of the window and the quality of the construction have more influence on indoor noise levels than balcony expansion itself.

KEYWORD

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Enclosed balcony
Indoor noise level
Balcony expansion

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1. Introduction

According to the statistics in 2010 from the Korean National Statistical Office, 27.3 % of households are living in single house, 59.0 % in apartments and the rest 13.7 % are in row house, multi-family house, and other houses. In particular, the proportion of apartments has been continuously increasing from 47.7 % in 2000 and 53.0 % in 2005. As such, improvements of the quality of indoor environment in apartments, where a majority of citizens live, would have a significant effect on quality of life.

Balconies in apartments generally allow exposure to outside air, unhindered by windows. However, in Korea, many residents installed windows to create an enclosed balcony that has greater utility. Nevertheless, such balconies act as a buffer space to the outside environment and thus have important roles in heat and sound insulation. However, with legalization of apartment balcony expansion in 2006 in Korea, many households chose to reduce or eliminate their enclosed balconies to increase the interior are without having to actually include this space in the legally registered floor space. This is interpreted as an advantage in spatial use by residents.

The statistical data[1] from the National Environmental Dispute Resolution Committee revealed that 86% of environmental disputes in 2010 by end of December were associated with by noise and vibration. Of the major forms of damages claimed, 39% were solely associated with psychological distress and 23% were a combination of psychological and building damages. Thus, over 60% of all damage claims were associated with psychological distress. In addition, 53% of disputes occurred in major metropolitan areas such as Seoul, Gyeonggi, and Incheon. This suggests that noise and vibration issues are endemic to large cities and have a significant psychological impact on the populace. Furthermore, studies on residential environment noise[2] have shown that road traffic is the most frequently cited cause of annoyance among exterior noises. Such noise was found to have bad effects on activities that require concentration such as reading and having a conversation as well as on sleep.

In Korea, Article 2 of Enforcement Decree of the Framework Act on Environmental Policy and Article 9 of Regulations on Standards, etc., of Housing Construction regulates standards for exterior noise in residential apartments. In particular, the noise level in an apartment complex must be less than 65 dB(A). However, if it crosses this limit, the standards must be satisfied by appropriate soundproofing such as the addition of soundproof walls. In addition, the indoor noise level must be under 45 dB(A) for residences on the sixth floor and above. Considering the fact

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that exterior noise levels for roadside apartments in cities is about 70~80 dB(A)[3], a reduction of about 25~35 dB(A) must be achieved by the exterior walls.

However, for apartments with enclosed balconies, most of exterior wall is occupied by the balcony window. Hence, the sound insulation performance of window strongly determines the indoor noise level. Data from laboratory tests show that, on average, a single window has a sound attenuation of about 20~30 dB and a double window achieves about 30~40 dB[4]. However, real-world attenuation may differ with the type of exterior sound source and differences in construction quality. For evaluation of sound insulation performance against airborne noise, the ISO 717-1[5] standard requires expression of performance using the spectrum adaptation terms C and C_{tr}, which reflect the type of sound source. For apartment houses in Korea, effective sound insulation through the balcony, which acts as a buffer space, will be lost if the balcony is eliminated. Thus, studies on the effects of such changes to the balcony on the indoor environment are necessary.

Most studies on the effects of balcony space expanding are focused on the thermal environment[6)7] and sound environment[8]. Indeed, many studies are being conducted to improve performance of balcony windows. However, when the buffer space is eliminated by expanding the balcony, the role of exterior-facing window becomes more important. Therefore, the performance of window becomes extremely important factor for increasing habitability.

Though there are differences among nations, apartments outside Korea usually do not have a window installed on the balcony. The window is only installed between the balcony space and the interiors. Therefore few such studies have been conducted outside Korea. Such studies on the influence of the balcony shape[9] as well as on the characteristics of sound sources and on the sound insulation performance of windows have been conducted[10].

This study aimed to analyze the sound insulation characteristics of the balcony window and the distribution of indoor noise in apartments to determine the effects of balcony expanding and determine whether windows can provide sufficient sound insulation. On the basis of the results, more reasonable standard for balcony windows could be suggested.

2. Measurement and Rating Method

Currently, the international standard for measurement of exterior noise in apartments (ISO 10140-5) is identical to the Korean standard (KS F 2235)[11]. Measurement of airborne sound insulation performance in apartments can be done on the window or on exterior walls including a window. The global method is used to compute exterior and interior sound pressure level differences under real conditions. The measured sound pressure level difference is classified according to the type of sound source, reverberation time of the test room, and the standard sound absorption power of the receiving room.

(1) Standardized sound pressure level difference ($D_{2m,nT}$) : Sound pressure level difference corresponding to reverberation time of the receiving room.

$$D_{2m,nT} = D_{2m} + 10\log\left(\frac{T}{T_0}\right),\ T_0 = 0.5s$$

(2) Normalized sound pressure level difference ($D_{2m,n}$) : Sound pressure level difference corresponding to standard absorption of receiving room.

$$D_{2m,n} = D_{2m} - 10\log\left(\frac{A}{A_0}\right),\ A_0 = 10m^2$$

The measured sound pressure level difference is regulated by the ISO 717-1:1996 and KS F 2862:2002 standards[12]. The rating method affords a single-number value for the sound reduction index R and the sound pressure level difference D. The spectrum adaptation terms are separately regulated for different sound source characteristics. Single-number quantity for airborne sound moves the reference curve for 1/3 octave band measurement result in vertical directions by 1 dB. Reference curve is moved upwards as much as possible without the sum of values falling short of reference curve in 16 1/3 octave bands (100-3150 Hz) exceeding 32.0 dB. The single-number quantities (R_w, R'_w, $D_{n,w}$, and $D_{nT,w}$) are the values of reference curve in decibel at 500 Hz.

The spectrum adaptation terms (C and C_{tr}) are used to evaluate sound insulation performance in extremely small steps over the frequency, with consideration for sound sources with diverse spectra such as pink noise and road traffic noise. They are calculated as follows:

$$C = X_{A,1} - X_W$$

where $X_{A,1}$ is the difference in the value computed by adding the frequency characteristics A to the sound pressure level between the sound source room and receiving room, when pink noise is generated in sound source room. Moreover, X_W is a single-number quantity based on a reference curve.

$$C_{tr} = X_{A,2} - X_W$$

where $X_{A,2}$ is the difference in the value computed by adding the frequency characteristic A to the sound pressure level between sound source room and receiving room for road traffic noise. In addition, X_W is a single-number quantity based on a reference curve.

3. Field Measurement

3.1. Sound Insulation Measurement for Balcony Windows

Measurement of the sound insulation performance of balcony windows was conducted at a new apartment complex site. Since the exterior wall is composed of the window and a load-bearing wall, all exterior noises are assumed to penetrate through the balcony window. The global method referred in chapter 2 was applied for measurement because the purpose of this study is to analyze the difference in sound pressure level between the interior and exterior through the balcony window. Road traffic noise was used as sound source for structures near roads that had sufficiently large road traffic noise. In apartments near roads with less vehicle traffic, a loudspeaker was used for measurement. Therefore there might be some differences in the sound insulation performance even for the same window because it depends on whether the loudspeaker or real traffic noise is used as a sound source. Moreover the sound level inside room may differ on which direction does the apartment face at road. That is why the sound level is different by the incident angle.

The devices used for the measurement were a directional loudspeaker (B&K Type 4224), nondirectional microphones (GRAS Type 40AR) and a multichannel signal analyzer (Rion SA-01). Figure 1 shows of the setup for the sound pressure difference measurements on first floor of apartments using a loudspeaker, indicating the positions of the loudspeaker and microphones. Using a standard method, the speaker was placed 7 m away from the exterior wall and placed at an angle of 45±5° from the vertical with respect to the wall. A microphone was positioned 0.5 m or further from the actual boundary surface or object to obtain an even distribution of sound throughout the room. A minimum of five receiving points set up with a separation of 0.7 m or greater between points. The exterior sound pressure level was measured at 1.5 m from the floor and 2 m from the center of the exterior wall.

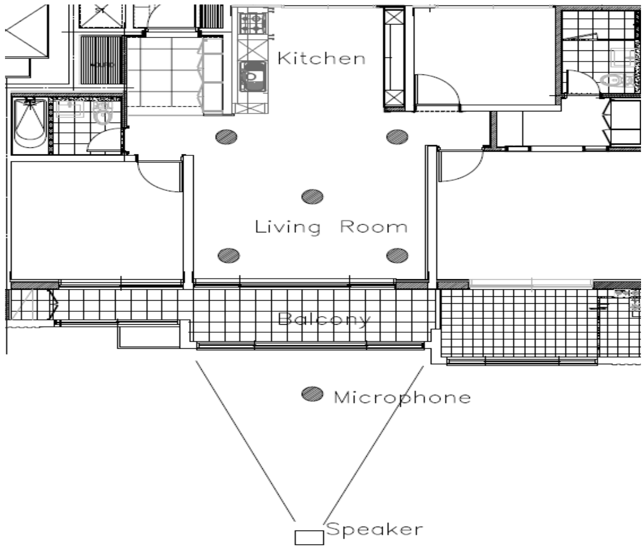

Fig. 1. Location of sound source and measurement position in apartment

3.2. Characteristics of Balcony Windows

Table 1 shows specifications for the apartments, rooms, and balcony windows being measured as well as the configuration of the window glass. To measure the effects of balcony expanding, we compared the sound insulation performance was compared before and after expanding in the same apartment.

Table 1. Detail information of window size and glass by apartment

Apt.	Area	Receiving room	Window size (L×H, mm)	Glass(Indoor/Outdoor, mm) * A : Airsapce of pairglass	Remark
YR-H	84㎡	Living room(LR)	4400×2300	16(5-6A-5)/16(5-6A-5)	expanded
	84㎡	Living room(LR)	4400×2300	16(5-6A-5)/16(5-6A-5)	
	75㎡	Living room(LR)	4400×2300	16(5-6A-5)/16(5-6A-5)	expanded
	75㎡	Living room(LR)	4400×2300	16(5-6A-5)/16(5-6A-5)	
MS-C	156㎡	Living room(LR)	4800×2200	22(5-12A-5)/22(5-12A-5)	expanded
	156㎡	Living room(LR)	4800×2200	16(5-6A-5)/22(5-12A-5)	
SW-H	51㎡	Living room(LR)	2800×2300	16(5-6A-5)/16(5-6A-5)	
	46㎡	Living room(LR)	2500×2300	16(5-6A-5)/16(5-6A-5)	
YD-H	108㎡	Living room(LR)	3900×2300	16(5-6A-5)/22(5-12A-5)	expanded
		Bed room 1(BR1)	3900×2200	16(5-6A-5)/16(5-6A-5)	
		Bed room 2(BR2)	2400×2300	16(5-6A-5)/22(5-12A-5)	expanded
	84㎡	Living room(LR)	3600×2300	16(5-6A-5)/22(5-12A-5)	expanded
		Bed room 1(BR1)	3700×2200	16(5-6A-5)/16(5-6A-5)	
SW-J	118㎡	Living room(LR)	3600×2300	16(5-6A-5) /16(5-6A-5)	expanded
		Bed room 1(BR1)	2200×1800	16(5-6A-5)/16(5-6A-5)	expanded
		Bed room 2(BR2)	2100×2300	16(5-6A-5)/16(5-6A-5)	
SM-H	158㎡	Living room(LR)	4500×2200	22(5-12A-5)/22(5-12A-5)	expanded
		Bed room(BR1)	3300×2200	22(5-12A-5)/22(5-12A-5)	expanded

Six newly constructed apartments in Gwangju and Jeollanamdo were chosen. Since the size of the balcony window differs within the same apartment depending on the plan, different plans within the same apartment complex were studied to determine the effect of size. The living room was chosen as the receiving room because the balcony adjacent to it is mostly commonly expanded. The bedroom was also included if its balcony was expanded.

The size of the window was proportional to the size of the interior space and ranged from 2100 mm to 4800 mm across. They were all similar in height, ranged from 2200 mm to 2300 mm. The external window was either 16 mm (5-6A-5) or 22 mm (5-12A-5) in thickness and the internal window was 16 mm thickness, except for the expanded SM-H and MS-C apartments. In the YR-H apartment, particularly measurements were performed in the balcony, living room, and kitchen in addition to around the balcony window to determine the changes in the interior and exterior sound pressure level difference in each interior space after balcony expanding.

4. Results and discussion

4.1. Comparison of Sound Insulation by Single Rating Method

The weighted standard sound pressure level difference ($D_{2m,nT,w}+C$) was computed from the interior and exterior pressure level difference (D_{2m}) and the interior reverberation time. Note that the spectrum characteristic C was applied when a speaker was used and C_{tr} was applied for YR-H, where actual road traffic noise was used.

Table 2. Sound level difference of balcony windows

Apt.	Area(m²)	Rsv. Room	Sound level difference(SLD) D_{2m}(dB)	Weighted standardized SLD $D_{2m,nT,w}+C$(dB)
YR-H	84m²	LR	24.4	32-1
	84m²	LR	29.1	36-1
	75m²	LR	33.9	41-2
	75m²	LR	32.4	43-1
MS-C	156m²	LR	40.5	45-1
	156m²	LR	44.1	48-1
SW-H	51m²	LR	32.3	34-1
	46m²	LR	32.6	34-1
YD-H	108m²	LR	44.0	43-1
		BR1	46.2	46-1
		BR2	39.1	40-2
	84m²	LR	44.8	44-1
		BR	52.6	51-1
SW-J	118m²	LR	41.0	42-1
		BR1	38.1	39-1
		BR2	38.2	39+1
SM-H	158m²	LR	40.0	43-1
		BR	37.7	41-1

* YR-H C (spectrum term) applies Ctr (road traffic noise spectrum)
** ■ Expanded structure

It was found that before expanding the balcony window had a weighted standard sound pressure level difference of about 33-50 dB, which reduced to about 31-44 dB after expanding. The non expanded structure had a D_{2m} value of 29-53 dB, which reduced to 24-45 dB after expanding. The mean reduction due to expanding was about 2-4 dB. This confirms that the balcony space improves sound insulation. In addition, a previous study showed that sound insulation performance could be improved by about 24 dB by adding sound absorption material only to the ceiling[8]. This means that difference in sound insulation performance from expanding can be increased further with balcony space.

4.2. Comparison of Sound Insulation by Balcony Expanding

Since the configuration of the balcony window differed according to how the balcony was expanded, it was explored the effects on the sound insulation performance, as shown in Fig. 2. In general, the sound insulation performance after expanding is lower than before expanding. Since road traffic noise was used as the sound source for YR-H, its sound insulation performance was somewhat lower than other cases that used a speaker[13]. However, when comparing the relative difference before and after expanding, the sound insulation performance was significantly degenerated after expanding. In the Fig.2 the open symbols indicate the sound insulation performance before expanding and the closed symbols indicate the performance after expanding.

Figure 3 compares the using weighted standard sound pressure level difference before and after expanding. Here, the results for the bedrooms in YD-H and SW-J are included for comparison. As shown in the figure, the sound insulation performance degraded after expanding in all cases. Of course, this is because the

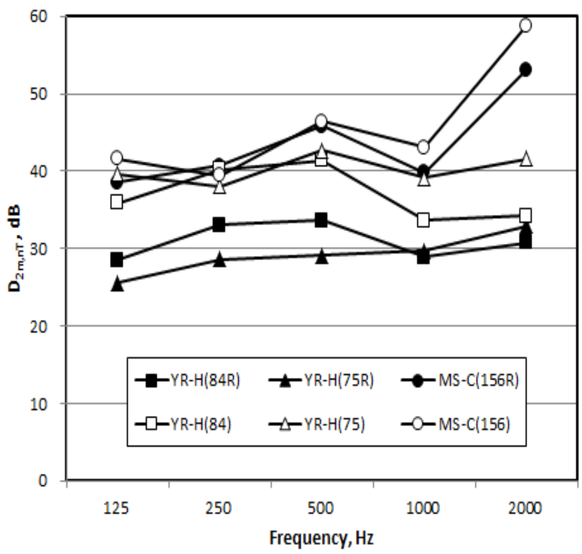

Fig. 2. Comparison of sound level difference before and after balcony expanding

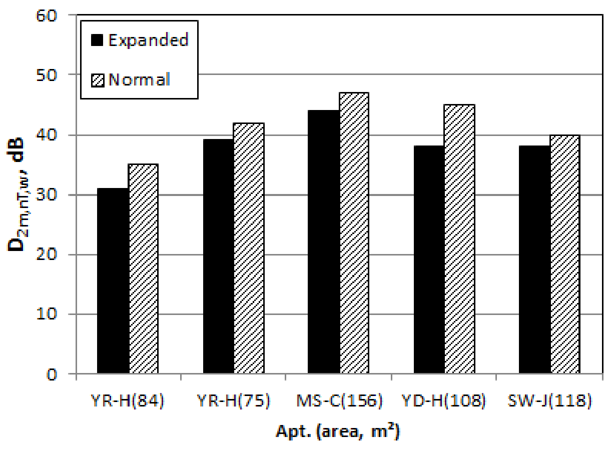

Fig. 3. Comparison of single number rating of level difference before and after balcony expanding

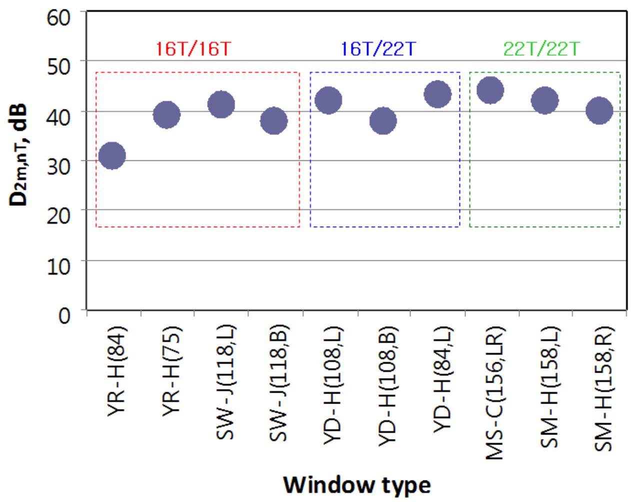

Fig. 4. Comparison of window sound insulation by glass thickness

configuration of the balcony window was not changed after expanding. The results can sufficiently differ if a window with a substantially different structure is used.

4.3. Comparison of Sound Insulation by the Type of Window Glass

As in Table 1, all balcony windows of apartments measured either used 16 mm or 22 mm thick pair glass. Comparison according to the configuration of glass(Fig. 4) shows that when both interior and exterior windows were made from 16-mm-thick panes, the sound insulation performance was the lowest. However, except for YR-H, it is difficult to determine the difference in sound insulation performance. In particular, since YR-H used road traffic noise as sound source, its sound insulation performance was 12 dB lower than that for apartments in which a speaker was used[12]. Considering this, it seems difficult to distinguish between windows according to the type of glass used.

4.4. Noise Level by Location inside Room

For YR-H, it was measured the sound pressure level difference in each interior space before and after balcony expanding. The measurement locations were 2 m outside the non-expanded balcony, inside the balcony, at the center of the living room, and in the kitchen. All windows were closed during the measurements. For the expanded balcony, measurements were performed at the same location, which was 1 m toward the living room from the window. Figure 5 compares the sound pressure level difference at each interior location with the value measured at the 2-m spot.

From this figure, the mean sound pressure level difference in the balcony space was about 23 dB in the expanded structure and about 14 dB before expanding. A difference of about 10 dB appears when the exterior window was a double or single window. However, trend in the sound pressure level difference was the opposite in the living room and kitchen. While the expanded structure showed

Table 3. Exterior sound level by the floor level of apartment

Region	Sound barrier	Exterior Noise Level (Leq, dB(A))				Note
		1F	5F	10F	15F	
Gwangju Gwangcheon E	×	67.0	68.5	69.8	69.0	This study
Gwangju Yangrim H	○	59.5	68.5	70.6	68.3	
Gwangju Pungam W	○	59.6	68.5	70.3	70.5	
Gwangju Yeomju J	○	65.4	72.5	70.7	71.7	
Gwangju Munheung D	○	70.9	81.4	83.9	84.1	Oh et. al.14)
Gwangju Ochi K	○	71.8	79.4	83.4	83.0	
Gwangju Dongrim P	○	64.8	69.5	78.0	79.9	
Cheonan Seongjeong W	×	66.4	67.1	73.3	75.4	
Cheonan Seongjeong D	×	68.0	78.0	79.0	77.5	
Pyeongchon N-1	×	64.4	70.7	68.2	65.6	Lee et. al.15)
Ilsan N-8	×	64.1	70.3	69.3	67.3	
Mokpo Seokhyundong A	×	65.9	74.4	74.2	73.4	Kim et. al.16)
Mokpo Sangdong C	×	63.1	73.6	75.8	69.9	
Incheon Seogu S	○	66.2	71.4	79.1	78.3	

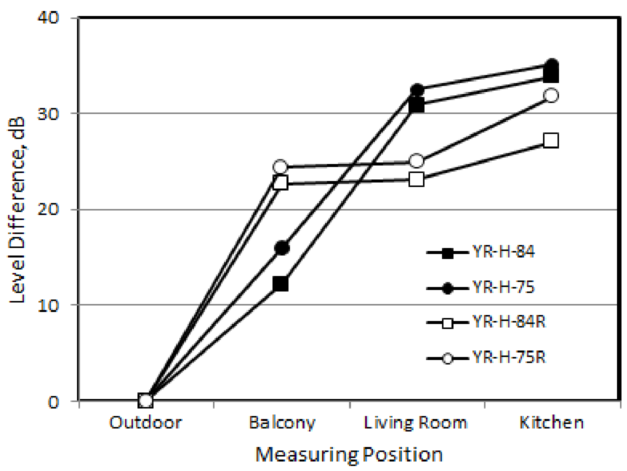

Fig. 5. Sound level difference in room compared with sound level in microphone installed apart from the window by 2 m

identical sound pressure level difference as the balcony, the non-expanded structure showed a rapid difference in the level with a mean difference of about 7 dB. Although the sound pressure level difference is further increased in the kitchen, the value is higher in the non-expanded structure. Such results suggest that indoor noise levels are generally elevated by balcony expanding.

4.5. Analysis of Indoor Noise Level for various Exterior Noise Levels

Thus far, the results have shown that expanding of the balcony may cause increase in indoor noise level. Next, it was examined whether the indoor noise level meets the minimum requirements for various exterior noise levels. The data was used the results of this measurement and from the existing literatures in terms of exterior noise levels like Table 3. Here only road traffic noise was considered. Exterior noise levels were measured on the first, fifth, tenth, and fifteenth floor of roadside apartments. A previous study reported noise levels as high as 70 dB(A) in four places in Gwangju City. According to the study by Oh[14], the noise level measured nearby a principle road in Gwangju exceeds 80 dB(A) and the noise level in Chunan is also close to 80 dB(A). Lee et al.[15] found similar results in Seoul, and Kim et al.[16] reported values close to 80 dB(A) in Incheon.

From these results, it was known that noise level exceeds the minimum requirement of 65 dB(A) for the fifth floor regardless of the presence of a sound barrier. Higher levels were also reported at higher floors. Thus, for floors above the fifth floor, the sound insulation performance of the balcony window must be better to meet the indoor noise level down to 45 dB(A).

Next, the indoor noise level was calculated on the basis of the sound insulation performance of the balcony window. Simple sound pressure level difference was used because the weighted standard sound pressure level difference takes reverberation time into consideration, which requires addition of indoor reverberation time into the calculation. The results show that for the exterior noise levels below 65 dB(A), the indoor noise level could meet the requirement. However, for the exterior noise levels around 80 dB(A), the level far exceed the limit level. Accordingly from the calculation of indoor noise level, the simulation performed with external noise levels from 70 dB(A) to 85 dB(A) in 5 dB(A) intervals. As shown in Table 4, in general despite the exterior noise levels higher than 70 dB(A), the indoor noise level satisfies the regulation of 45 dB(A). However, some apartments show indoor noise level higher than 45 dB(A) at exterior noise levels of 75 dB(A) or higher. Thus the sound insulation performance of the balcony window or indoor noise level depends more on the apartment than whether the balcony is expanded. Though expanded balcony led to a small reduction in sound insulation, the change is relative to the original structure. That is, an apartment with excellent sound insulation performance will generally retain

Table 4. Prediction of indoor noise level using measured exterior sound level and sound level difference of balcony window

Apt.	Area	Receiving room	Level Difference	Exterior Noise Level (dBA)				Remark
				70	75	80	85	
YR-H	84 m^2	Living room(LR)	24.4	45.6	50.6	55.6	60.6	expanded
	84 m^2	Living room(LR)	29.1	40.9	45.9	50.9	55.9	
	75 m^2	Living room(LR)	33.9	36.1	41.1	46.1	51.1	expanded
	75 m^2	Living room(LR)	32.4	37.6	42.6	47.6	52.6	
MS-C	156 m^2	Living room(LR)	40.5	29.5	34.5	39.5	44.5	expanded
	156 m^2	Living room(LR)	44.1	25.9	30.9	35.9	40.9	
SW-H	51 m^2	Living room(LR)	32.3	37.7	42.7	47.7	52.7	
	46 m^2	Living room(LR)	32.6	37.4	42.4	47.4	52.4	
YD-H	108 m^2	Living room(LR)	44.0	26.0	31.0	36.0	41.0	expanded
		Bed room 1(BR1)	46.2	23.8	28.8	33.8	38.8	
		Bed room 2(BR2)	39.1	30.9	35.9	40.9	45.9	expanded
	84 m^2	Living room(LR)	44.8	25.2	30.2	35.2	40.2	expanded
		Bed room 1(BR1)	52.6	17.4	22.4	27.4	32.4	
SW-J	118 m^2	Living room(LR)	41.0	29.0	34.0	39.0	44.0	expanded
		Bed room 1(BR1)	38.1	31.9	36.9	41.9	46.9	expanded
		Bed room 2(BR2)	38.2	31.8	36.8	41.8	46.8	
SM-H	158 m^2	Living room(LR)	40.0	30.0	35.0	40.0	45.0	expanded
		Bed room(BR1)	37.7	32.3	37.3	42.3	47.3	expanded

its characteristics after expanding. Overall, balcony space expanding does have an influence on indoor noise level, but of the type of window used and the air tightness are more important.

4.6. Considerations for Balcony Expanding

Balcony expanding became social trend, and most floor plans in the stage of design are considered to be expanded. Especially for the small type of apartment, it is one of the inevitable actions because smaller apartment needs more spaces. In spite of many advantages such as more space and low price per area, there are important factors that should be taken into consideration. In the point of acoustic environment among the factors, balcony expanding may cause the sound insulation lower then sound level inside room higher. In the long run, the windows constructed facing main exterior noise should be considered, whether they are proper type or have suitable sound insulation performance. In addition, the airtightness must be guaranteed in most cases it tends to give higher thermal insulation as well as sound insulation.

5. Conclusion

The balcony space is an important buffer space for noise transfer in addition to heat transfer between interior and exterior spaces. With legalization of balcony expanding, residents began to remove balcony space to increase interior floor space. However, the effects of this change on the indoor environment have not been previously elucidated. Accordingly, this study was conducted as a part of environmental performance analysis to examine changes in acoustic environment after balcony expanding and to provide data for future balcony designs.

The result using the weighted standard sound pressure level difference showed a decrease of about 3 dB in sound insulation performance after expanding. However, comparison of different apartments showed that the construction quality and window have a much greater impact. Thus the sound insulation performance of the balcony window is basically influenced by balcony expanding though, the characteristics of the window and construction quality are more important. These factors are closely related to air tightness and sound insulation performance.

Exterior noise measurement results in cities and exterior noise levels from the literature were used as the basis for calculation of indoor noise level. Exterior noise levels were assumed to be 70, 75, 80 and 85 dB(A). It was found that for some structures, indoor noise levels exceeded the minimum requirement of 45 dB(A) for exterior noise levels above 80 dB(A). Thus, for apartments where exterior noise levels exceed 80 dB(A), it is necessary to increase the sound insulation performance of the balcony window to 40 dB ($D_{2m,nT,w}$) or higher.

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