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NOISE CONTROL FOR A BETTER ENVIRONMENT

Evaluation of transport related noise exposure to residents in Taiwan metropolitan area

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ABSTRACT

With increasing density of urban population and completion of railway construction, noise pollution has become an important issue in Taiwan in last decade. This study aimed to evaluate the relationship between railway noise, speed rate and noise effect in metropolitan areas in Taiwan. Both general and high-speed railway noise were measured in Taipei and Taichung metropolitan areas from 2017 to 2018. Analyses indicated that relationship between noise level and speed rate logarithm of the general railway train is 35 log(v), while that with high-speed railway is 30 log(v). And sound insulation between indoor and outdoor under closed door/window condition is 20 dB(A), while with open door/window condition is 10 dB(A) in residential area near railway. Taiwan Environmental Protection Administration (EPA) planned to launch technical approaches including improved solar panel noise barriers along railway and active control type soundproof windows to achieve environmental sustainability goals for noise, carbon and air pollution reduction.

Keywords：Noise, Railway, Metropolitan
I-INCE Classification of Subject Number: 13

1. INTRODUCTION

Due to increasing density of urban population, various living lifestyles and intensive use of land in Taiwan, newly constructed residential buildings may be close to main traffic roads in metropolitan areas. Railroad related noise has become an important issue in Taiwan in last decade. In order to reduce impact of noise pollution on residents along railroad, it is necessary to understand the characteristics of noise sources, sound insulation between indoor and outdoor under closed door/window condition residential area. This research aimed to evaluate the relationship between railway noise, speed rate and noise effect in metropolitan areas in Taiwan.

According to High-Speed Ground Transportation Noise and Vibration Impact Assessment by Federal Railroad Administration (FRA) of US Department of Transportation, the effective height of radiation rolling noise between wheels and rails

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is 0.6m above the orbital plane. With increasing speed of train, the increment of rolling noise is much bigger than that of propulsion noise. The regression coefficient of speed and railway noise was 30. When the speed reached to 290 km/h, pneumatic noise becomes more apparent by high-speed airflow across the train. And typical relationship is 60 to 70 times of rate logarithm by train [1].

In Japan, Nagakura Kiyoshi and Zenda Yasuo identified four noise sources of high-speed railway, which included wheel-rail noise, locomotive noise, pneumatic noise, and power collection system noise. And proposed a calculation formula for noise source SWL[2]. A French study found that the rolling noise is the main noise source of high-speed trains (TGV) with increasing speed [3]. And correlation coefficient of speed and railway noise was 0.93 with the regression coefficient was 30.4[4, 5, 6]. The causes of noise level difference between indoor and outdoor environment are related to many factors including building characteristics, outer wall types, room capacity, outdoor noise sources and window types. According to our comprehensive analysis of literatures, sound insulation between indoor and outdoor under open and slightly open window condition were 10 dB(A) and 15 dB(A). However, sound insulation between indoor and outdoor was about 25 to 30 dB(A) with tilt-in windows(Table 1).

Table 1. *Comparison of results of indoor/outdoor L_{eq} noise level difference found in foreign related researches* [7、8]

Researcher	Noise source	Window Position dB(A)		
		open	tilted	closed
DLR	Freight Trains	11.3 (4)	18.6 (10)	30.1 (13)
	Trains Passenger	11.9 (4)	18.0 (10)	29.7 (13)
	Road	11.6 (4)	17.7 (10)	30.1 (13)
DLR	Road	13.4 (4)	13.7 (32)	27.0 (15)
	Aircraft	10.0 (4)	15.3 (32)	25.6 (15)
EEA		5~10	10~15	
Barbara Locher	Road	10.0 (115) 1.7~17.3	15.8 (116) 8.7~21.7	27.8 (76) 16.2~38.0
Researcher	Noise source Type	Window Position dB(A)		
		open	tilted	closed
Scamoni	Reference Road			31.2 (334)
Ryan	Road	10.7 (11) 5.4(vacant)~14.7		
Maschke	Aircraft		12	
FOEN	Aircraft		15	25
Jansen	Aircraft		15	
Pabst	Aircraft			24~35

Note: Figures in parentheses refer to number of positions analyzed. DLR stands for German Aerospace Center. FOEN stands for Federal Office for the Environment (Switzerland). EEA stands for European Environment Agency.

2. Research method

2.1 Characteristics of train noise sources

(1) In-situ measurement

We measured noise level of various types of trains with general and high-speed railways (THSR 700T series) under different speeds with the following conditions: (a) measuring instrument: RION NL32 noise meter, (b) measuring time and indicator: A-weighted slow feature event equivalent sound level (L_{Aeq}), (c) measuring sites: wayside embankment sections without parapet walls or soundproof walls and horizontal alignment is straight line without switches, (d) measuring location: for general railway, the noise meter is about 3.8m horizontally from the center line of rail, and 0.5m vertically from the track surface (as shown in Figure 1). For high-speed railways, the noise meter is about 25m horizontally from the the center line of rail,and 1.5m vertically from the track surface (as shown in Figure 2), (e) measured types of trains (as shown in Table 2): for general railway, 14 trains included local trains, Tze-Chiang Limited Express, Chu-Kuang Express, and Puyuma Express. For high-speed railway, 21 THSR trains included northbound 700T and southbound 700T, (f) speeds of trains: 48.0 to 115.2 km/h for general railway, 157.6 to 281.3 km/h for THSR.

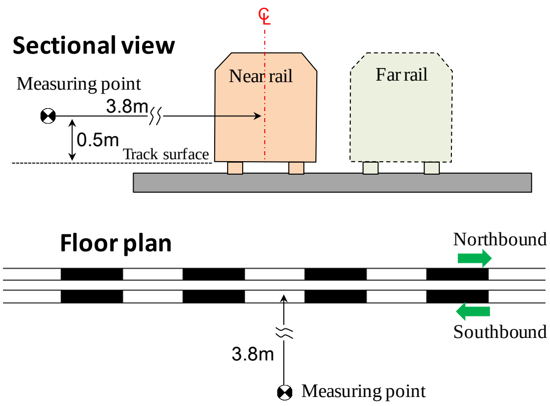


Figure 1. *Diagram of in-situ measurement position for general railways*

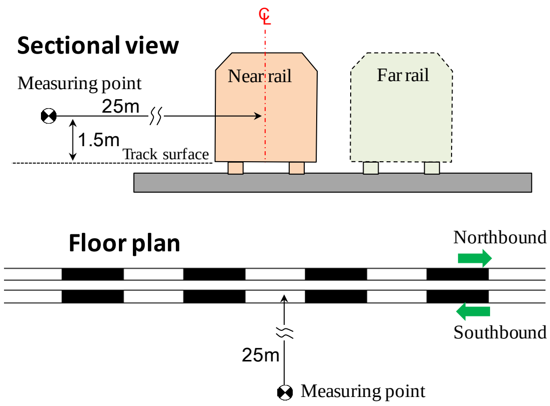


Figure 2. *Diagram of in-situ measurement position for THSR*

Table 2. *Number of measurements of train noise sources*

Direction	1. General Railway				2. THSR
	(1) Local trains	(2) Tze-Chiang Express	(3) Chu-Kuang Express	(3) Puyuma Express	(1) 700T
Southbound	9	3	1	1	11
Northbound	—	—	—	—	10

(2) Theoretical formula

This study aimed to explore the logarithmic relationship between increments of train event equivalent sound level (L_{Aeq}) with increasing speed (general equation is shown in Equation 1). We performed a linear regression analysis on measured results to obtain the regression coefficient, namely the relationship between noise level and train speed.

$$L_{Aeq}(v) - L_{Aeq}(v_0) = k \times \log(v/v_0) \qquad \text{Eq. 1}$$

v refers to train speed (km/h);
v_0 refers to reference train speed;
k refers to regression coefficient.

2.2 Sound insulation between indoor and outdoor

The main purpose of measurement is to understand the sound insulation (transmission loss) and indoor/outdoor sound attenuation of the building under open or closed door/window condition (Figure 3). RION NL-32 noise meter (Japan) is used for measurement. For the road system, condition of measurement such as 5-minute A-weighted equivalent sound level L_{Aeq} (20 to 20,000 Hz), maximum noise level L_{Amax}, and fast feature are adopted. As for the railway system, noise event A-weighted equivalent sound level L_{Aeq} (20 to 20,000 Hz), maximum noise level L_{Amax}(event), and slow feature are adopted. Measures of each train (about 3 trains) were averaged. And 26 measurements were made in total (Table 3). Indoor and outdoor measurements were made simultaneously in order to catch the same noise event. The outdoor noise meter was placed about 1.5m vertically from the extension line of the ground or floor and about 1.5m horizontally from the wall. The indoor noise meter was placed about 1.5m vertically from the ground or floor and about 1.5m horizontally from the door and window.

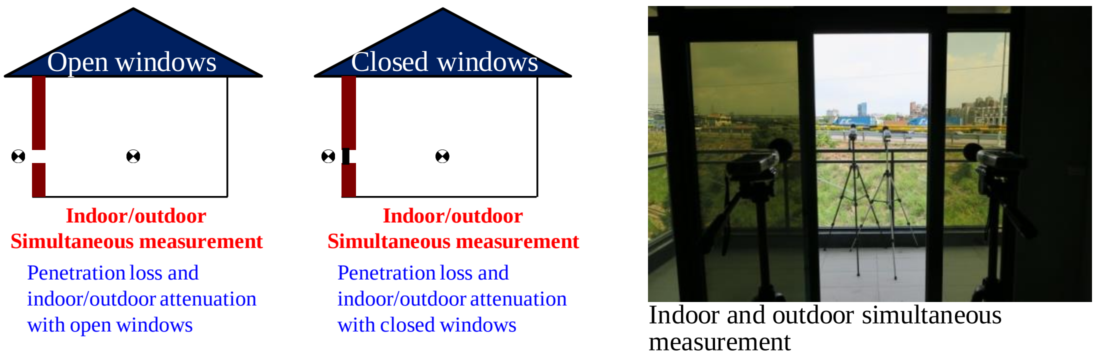


Figure 3. *Diagram of conditions for indoor/outdoor noise measurement in residential areas*

(Note: ⊗ refers to the sound receiving point for indoor/outdoor simultaneous measurement)

Table 3. *Number of measurements of indoor/outdoor noises in residential areas*

Type of transport	General roads	Ground road transportation system		Ground rail transportation system		
	Urban roads	Freeway	Expressway	MRT	General railway	THSR
Measurements	1	7	2	4	10	2

3. Results

3.1 Regression analysis between noise level and train speed on general railways

The relationship between noise level and rate logarithm of the southbound near-rail train is shown as Figure 4. And regression formula is shown as Equation 2. We found that the regression coefficient (k) is 35.1 and correlation coefficient is 0.93. With increasing train speed, the increment of raild noise level has a highly positive trend.

$$y = 35.112x + 22.637 \quad \text{Eq. 2}$$

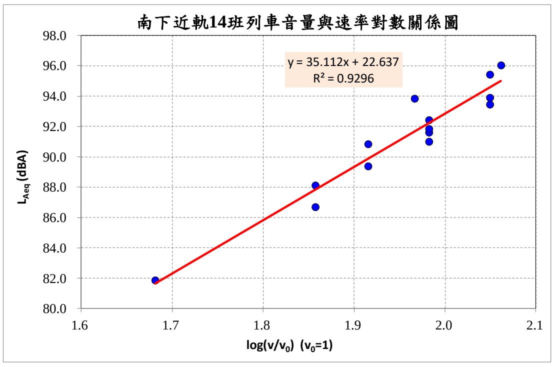


Figure 4. *Relationship between noise level and rate logarithm of general railways southbound near-rail trains*

3.2 Regression analysis between noise level and train speed on THSR

(1)Southbound near-rail train

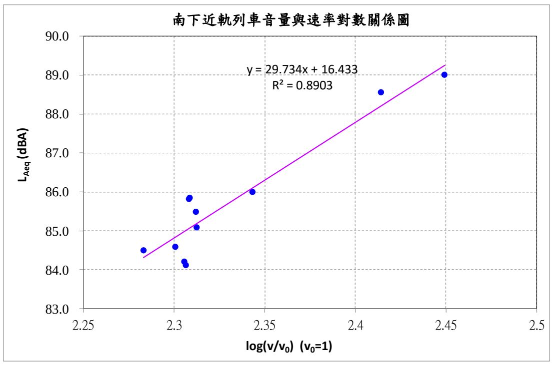
The relationship between THSR noise level and rate logarithm is shown as Figure 5. The range of speed we measured was from 191.9 to 281.3 km/h. The regression formula is shown as Equation 3. The regression coefficient (k) is 29.73 and correlation coefficient is 0.89.

$$y = 29.734x + 16.433 \quad \text{Eq. 3}$$

(2)Northbound far-rail train

The relationship between noise level and rate logarithm is shown as Figure 6. The range of speed is from 157.6 to 262.9 km/h. The regression formula is shown as Equation 4. And the regression coefficient (k) is 30.87 and correlation coefficient is 0.83.

$$y = 30.869x + 12.542 \quad \text{Eq. 4}$$



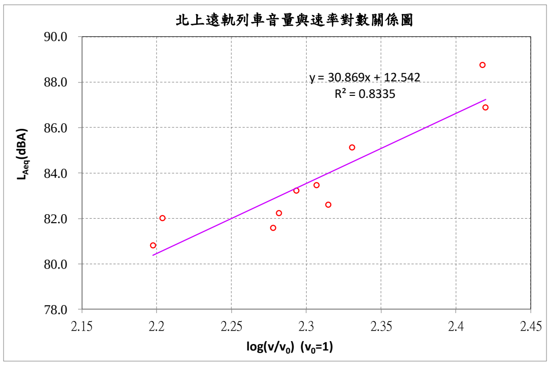


Figure 5. *Relationship between noise level and rate logarithm of THSR southbound near-rail trains*

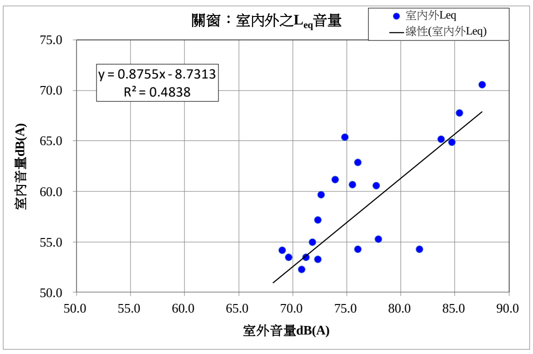
Figure 6. *Relationship between noise level and rate logarithm of THSR northbound far-rail trains*

3.3Indoor and outdoor noise level

(1)Sound insulation with closed doors/windows

We measured railway noise both indoor and outdoor simultaneously (20 to 20,000 Hz) under closed doors/windows condition. Figure 7 and Figure 8 showed the correlation coefficient less than 0.5, which indicated low linear correlation between the two variables (indoor/outdoor noise levels). It means that noise was more affected by the path media (door/window frame and glass) passing through doors and windows. The indoor/outdoor noise level difference under closed doors/windows condition was mainly related to the door and window frame materials and glass types. And average sound insulation is 20 dB(A).

For air as sound transmission medium, adequate soundproof windows, and good construction quality, it should be sufficient to block the noise from enter into the building. However, low frequency noises (20 to 200 Hz) may be transmitted into or out of the building through other building structures than windows. Besides, since low frequency noises have longer wavelength, only structures with bigger surface density can effectively block the sound transmission.



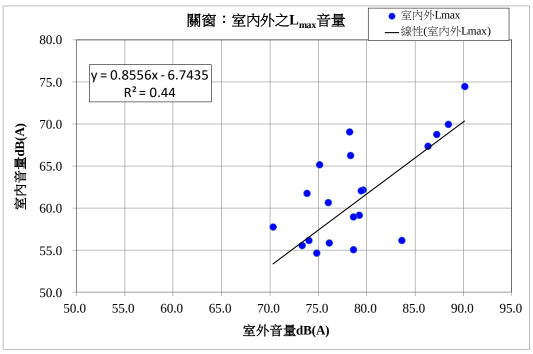


Figure 7. *Linear regression of indoor/outdoor L_{eq} (20 Hz~20,000 Hz) with closed (doors) windows*

Figure 8. *Linear regression of indoor/outdoor L_{max} with closed (doors) windows*

(2)Sound insulation with open doors/windows

We also measured indoor and outdoor railway noise simultaneously (20 to 20,000 Hz) with open doors/windows. Figure 9 and Figure 10 showed the correlation coefficient is 0.87, which indicated high linear correlation between the two variables (indoor/outdoor noise levels). We found that noise level less affected by the path media (door/window frame and glass) through doors and windows. As shown by above preliminary results, the factors that affect the indoor/outdoor noise level difference with open (doors) windows are mainly related to the indoor space, sound absorbing ability, and the position of opened doors and windows. According to the preliminary measuring results, average sound insulation with closed (doors) windows is 10 dB(A).

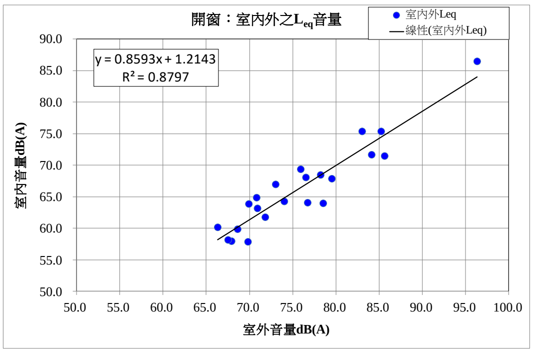


Figure 9. *Linear regression of indoor/outdoor* L_{eq} *(20 Hz~20,000 Hz) with open (doors) windows*

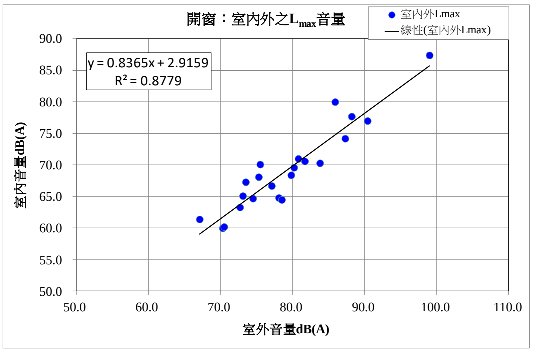


Figure 10. *Linear regression of indoor/outdoor* L_{max} *with open (doors) windows*

4. Discussion

4.1 General Railway

The regression analyses on different train types of general railways measurements showed that the relationship between noise level and rate logarithm is about 35 times (35log(v)), which is slightly higher than the previous studies findings in US, Japan, and France (30 times). The train type used in our study is Electric Multiple Unit (EMU), of which the traction power is separately deployed on each car. In other words, the power components or air compressors are evenly distributed under the train. Since the power of the train belonged to the dispersed type, the noise level may also be affected by power components.

Previous mentioned regression empirical formula (Equation 2) was used to estimate the train noise level under different speeds, such as 50 km/h, 60 km/h, and 110 km/h (as shown in Table 4). The estimation point was located about 3.8m horizontally from the near-rail centerline and about 0.5m vertically from the track surface, which was pretty close to the noise source end. It can be estimated that every increase of 20 km/h of train speed may cause noise level to increase 3 to 5 dB(A).

Table 4. *Estimation of general railway train noise level under different speeds*

Operating speed (km/h)	50	60	70	80	90	100	110
Southbound near-rail noise : dB(A)	82.3	85.1	87.4	89.5	91.3	92.9	94.3

Note: The estimation point is about 3.8m horizontally from the near-rail centerline and 0.5m vertically from the track surface. No parapet walls or soundproof walls built beside the rail track.

4.2 High-speed Railway

The regression analyses on measured results on THSR 700T showed that the relationship between noise level and rate logarithm is about 30 times (30log(v)), which is consistent with previous studies in U.S., Japan, and France, indicating that this feature existing in wheel-rail rolling noise of all high-speed trains from different countries and does not apparently change with the locations or train types. The speed range we adopted in this study was from 157.6 to 281.3 km/h. Due to limitation of THSR 700T's operating speeds, the train noise level under higher speeds cannot be measured. However, the results show that even when the train speed reaches 280 km/h, wheel-rail rolling noise is still the main noise source.

The above-mentioned regression empirical formula (Equation 3 and 4) was used to estimate train noise level under four THSR operating speeds (285 km/h, 230 km/h, 170 km/h, and 120 km/h), and results are shown in Table 5. We found the estimated noise level reducing with the decrease of train speed. Particularly, when the train speed decreases to 170 km/h, the noise level at the estimation point (about 25m horizontally from the near-rail centerline and about 1.5m vertically from the track surface) has reduced to be lower than the maximum mean noise level (85 dB(A)) stipulated by the EPA Noise Control Standards. The results may serve as reference for determining train operating speeds at noise-sensitive sections without affecting the operating practices and train dispatching when soundproof walls do not work very well or are not adopted.

Table 5. *Estimation of THSR train noise level under different speeds*

Operating speed (km/h)	Southbound near-rail noise level	Northbound far-rail noise level : dB(A)
285	89.4	88.3
230	86.7	85.4
170	82.8	81.4
120	78.3	76.7

Note: The estimation point is about 25m horizontally from the near-rail centerline and 1.5m vertically from the track surface. No parapet walls or soundproof walls built beside the rail track.

4.3 Indoor/outdoor noise level difference

In the metropolitan area, the equipment we used that tends to produce low frequency noises (such as cooling tower, air conditioning system, exhaust fan, and pumping motor), which was often used and over development causing more residential communities to be located next to traffic arteries or overpasses. Therefore, the noise made by these mechanical power machines in operation and the acoustic resonance generated by transportation may be transmitted to people's residence through building structures, such as roof beams, columns, floors, and walls.

In addition, thin building structures, inadequate cement grouting, and cracks in the wall may also be possible factors that cause increase of low frequency noises or poor soundproofing performance. On account of the above possible influencing factors, the analyses on measured noise values under closed (doors) windows condition showed that sound insulation for full frequency noise is better than that for low frequency noises (Figure 11). It indicated that the soundproof effect for full frequency noise is better. And analyses on measurements with condition of open windows (Figure 12) showed that the indoor/outdoor sound insulation of full frequency noises and low frequency noises didn't show a specific regularity. Therefore, doors and windows are important factors that influence soundproofing performance.

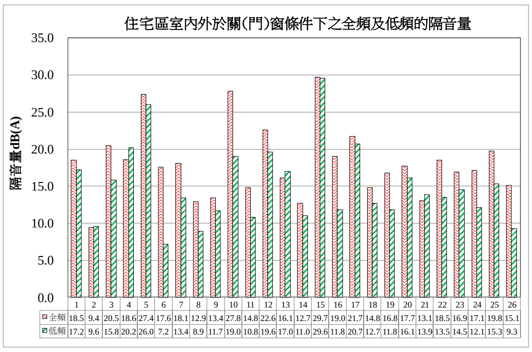


Figure 11. *Noise level difference (sound insulation) of full frequency (20 Hz~20,000 Hz) and low frequency (20 Hz~200 Hz) indoor/outdoor L_{eq} with closed (doors) windows*

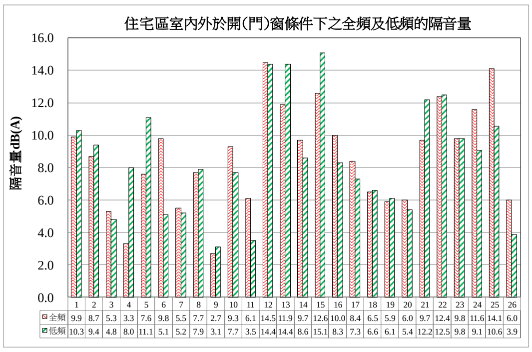


Figure 12. *Noise level difference (sound insulation) of full frequency (20 Hz~20,000 Hz) and low frequency (20 Hz~200 Hz) indoor/outdoor L_{eq} with open (doors) windows*

5. Conclusions

5.1 Characteristics of train noise sources

The regression analyses on measurements with different train types of general railways showed that the relationship between noise level and rate logarithm was 35 times (35log(v)), slightly higher than previous findings on high-speed rail wheel-rail noise from the US, Japan, and France. The relationship between noise level and rate logarithm of THSR trains is about 30 times (30log(v)), which is consistent with previous findings from other countries.

With preliminary empirical regression formula, it can be estimated that every increment of 20 km/h in speed of general trains may cause the noise level to increase about 3 to 5 dB(A). When the speed of THSR trains decrease to 170 km/h, the maximum mean noise level of operating trains should be lower than 85 dB(A) stipulated by the EPA Noise Control Standards. These results may serve as reference for determining the thinking direction of operation and management under the conditions of without spending huge noise countermeasures cost or affecting the train dispatching operation (for example, increasing train speed at sections with less population).

The 30log(v) relationship between noise level and rate logarithm is still true at least when the train speed reaches 280 km/h, which confirmed that wheel-rail rolling noise was the main noise source of THSR trains. Since the wheel-rail rolling noise falls into the frequency band that is sensitive to human ears, this noise source is in need of urgent improvement. Therefore, control measures should be formulated in accordance with the characteristics of this noise source.

5.2 Indoor/outdoor noise level difference

In both actual measurement and regression analyses, the indoor/outdoor noise level difference with closed (doors) windows is about 20 dB(A), while that with open (doors) windows is about 10 dB(A). In other words, the noise level difference with open or closed (doors) windows is about 10 dB(A). With closed (doors) windows, the noise level difference is more affected by path media (door/window frame and glass) passing through doors and windows. On the other hand, with open (doors) windows, the noise level difference is mainly related to the indoor space, sound absorbing ability, and the position of opened doors and windows.

The results of in-situ measurement showed that the sound simulation of doors and windows is less than the Sound Transmission Class (STC) used in the lab. The soundproof effect of doors and windows is better for full frequency noises (20 Hz to 20,000 Hz) and relatively poor for low frequency noises (20 Hz to 200 Hz).

5.3 Recommendations

It is necessary to conduct complete measurements repeatedly and obtain empirical results of various train types and speeds to further verify the relationship between noise level and train speed. In future, it’s advisable to conduct measurements through microphone array in order to clarify noise characteristics and contribution of each noise source in trains of both general railway and high speed railway.

If the doors and windows in residential buildings are usually closed, it is advisable to improve sound insulation by using strengthened frame materials for doors and windows and adopting glass types with higher STC. On the other hand, if the doors and windows of the residential buildings are usually opened, it needs to improve sound insulation by adjusting the position of opened doors and windows and adopting mechanical ventilation. In this year, Taiwan EPA planned some innovative and sustainable noise reduction practices to deal with environmental traffic noise effect to residents.

(1) Solar panel noise barriers

A. First stage:

We will use green-energy material (i.e. solar panel) to modify the existing soundproof walls or use green-energy material modules to the design of new noise barriers. And evaluate the feasibility of applying green-energy materials to the ground transportation system for the purpose of reducing pollution, carbon emission, and noise.（Landscape simulation as Figure 13）

B. Second stage:

Use estimation models to analyze the effectiveness of air pollution, carbon, and noise reduction when applying renewable energy to the ground transportation system. And also use the measured results to evaluate the feasibility of renewable energy to other systems.

(2) Active control type soundproof walls

A. First stage:

Run a trial on active soundproof walls for the purpose of reducing noise levels (including low frequency noises) without closing the windows. The goal of noise reduction is over 10 dB(A) in order to allow the residents to feel the same quietness as windows are closed and a quiet and ventilated indoor space so as to reduce their use of air conditioning and electricity expenses.

B. Second stage:

In future, we hope that different noise can be identified and to ensure that necessary sound not be eliminated, such as emergency alarm. Besides, consider the possibility of integrating soundproof functions into personal mobile devices to allow residents to eliminate the annoying noises if they want.

6. Acknowledgements

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Pre-construction	After construction

Figure 13. *Landscape simulation of solar panel noise barriers near train station*