Case studies of innovative window and balcony design for traffic noise mitigation

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ABSTRACT

Traffic noise is one of the critical environmental issues in a morden city. Highrise residential buildings need to be provided with good sound mitigations in order to reduce the noise from traffic. Other than building a big roadside noise barrier, some passive mitigation measures at the residential unit itself could be a good choice for controlling traffic noise ingress without compromising natural ventilation. Different types of specially designed acoustic windows and balconies have been studied to cater address the noise problem. Tests have been carried out to quantify the acoustic performance of those windows and balconies.

1 INTRODUCTION

Hong Kong is a famous moden city with many highrise buildings for residential uses. Due to the limited land supply in downtown areas, many of the new residential buildings are inevitably located near infrastructure development. Consequently traffic noise is one of the major noise pollution problems in Hong Kong. While typical noise mitigation techniques such as noise barriers and semi-enclosure of the road require urban planning and are subject to space limitations, mitigation at the receiver by means of passive noise reduction devices on the building facade are not subject to these constraints. For these reasons they can be regarded as the ultimate measure for traffic noise control.

Typical noise mitigation by architectural fins have been adopting in Hong Kong, but thie method could only provide limited performance for traffic noise reduction. Innovative noise reducing windows and balconies are the prevailing measures for providing better traffic noise mitigation. Additionally these devices could maintain adequate openings for ventilation.

In this study, two types of High Level Top-Hung Windows and an enhanced acoustic balcony were used in full scale off-site mock up tests to analyse the noise reduction performance of these devices, compared with conventional room openings for natural ventilation.

2 MOCK-UP MEASUREMENTS

2.1 Offsite Mock-up testing for High Level Top-Hung Window (case 1)

The mock-up unit was erected at outdoor area in Hong Kong. To simulate the noise reduction as close as possible to the future development, the mock-up unit was constructed in 1:1 in scale as far as possible. Loudspeakers with white noise were used to simulate the line source from outdoor traffic. Figure 1 illustrates the offsite mock-up room and the line of loudspeakers.

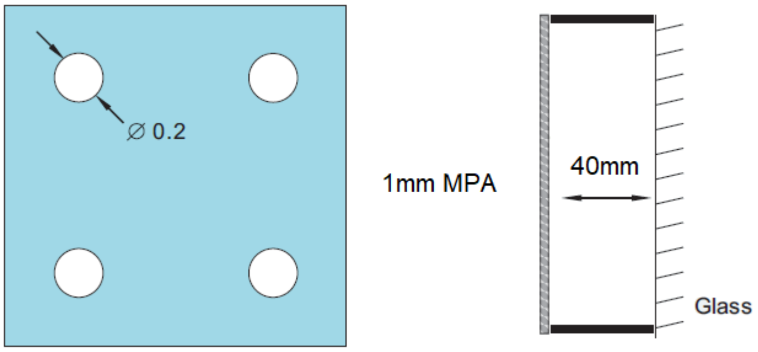

Source (Author, 2019)
Figure 1: Offsite mock-up room and the line of loudspeakers (case 1)

The mock-up room was enclosed with full height drywalls and solid ceiling and floor, with internal and exterior wall finishing as similar as possible to the future development. The drywalls were recommended to be constructed with 0.4mm steel plate, 1 layer of gypsum broad and layer of 50mm Rockwool and 2 layers 12mm gypsum, leading to the overall sound transmission class of at least STC43. No opening was allowed in the mock-up room, except windows and entrance door. The envelope was sealed with silicon sealant to eliminate flanking sound paths. No furniture was provided in the mock-up room, whereas typical wall finishing (i.e. plaster finishing) and carpet flooring were applied in the mock-up room.

High level Top-Hung Windows constructed with horizontal/ vertical fins were installed in the mock-up unit to analyse the noise reduction performance for the scenarios summarized in Table 1. Microperforated panel absorbers (MPA) (Xiang YU, 2014) was proposed to be installed at the top-hung window pane so as to increase the noise reduction performance of the window. Design schematic of the MPA is illustrated in Figure 2. Typical sections of the window design are illustrated in Figure 3.

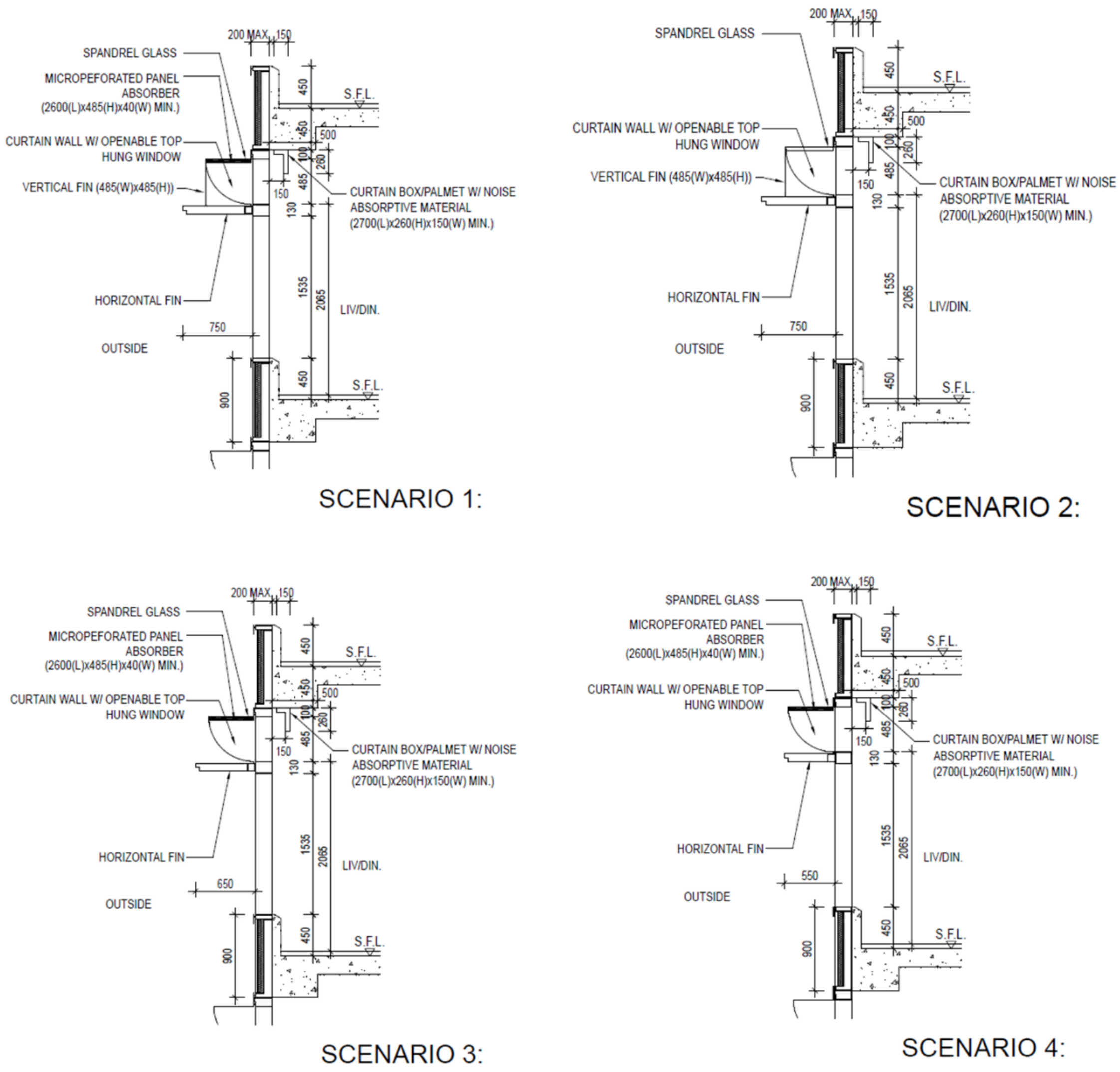
Table 1: Summary of Testing Scenarios for High level Top-Hung Window (case 1)

Scenarios	Descriptions
1	1. High Level Top-Hung Window 2. Window Opening of 2600mm(L) x 485mm(H) 3. 750mm horizontal fin 4. 485mm vertical fins 5. Sound absorptive Curtain box 6. Microperforated panel absorber (MPA)
2	1. High Level Top-Hung Window 2. Window Opening of 2600mm(L) x 485mm(H) 3. 750mm horizontal fin 4. 485mm vertical fins 5. Sound absorptive Curtain box
3	1. High Level Top-Hung Window 2. Window Opening of 2600mm(L) x 485mm(H) 3. 650mm horizontal fin 4. Sound absorptive Curtain box 5. MPA
4	1. High Level Top-Hung Window 2. Window Opening of 2600mm(L) x 485mm(H) 3. 550mm horizontal fin 4. Sound absorptive Curtain box 5. MPA



Sound Absorption Average (SAA): 0.56, Noise Reduction Coefficient (NRC): 0.55

Source (Author, 2019)
Figure 1: Design Schematic of MPA



Source (Author, 2019)
Figure 3: Typical Sections of High Level Top-Hung Window (case 1)

2.2 Offsite Mock-up testing for Enhanced High Level Top-Hung Window and Acoustic Balcony (case 2)

The mock-up unit was erected at outdoor area in Hong Kong. To simulate the noise reduction as close as possible to the future development, the mock-up unit was constructed in 1:1 in scale as far as possible. Loudspeakers with white noise were used to simulate the line source from outdoor traffic. Figure 4 illustrates the offsite mock-up room and the line of loudspeakers.

Source (Author, 2019)
Figure 4: Offsite mock-up room and the line of loudspeakers (case 2)

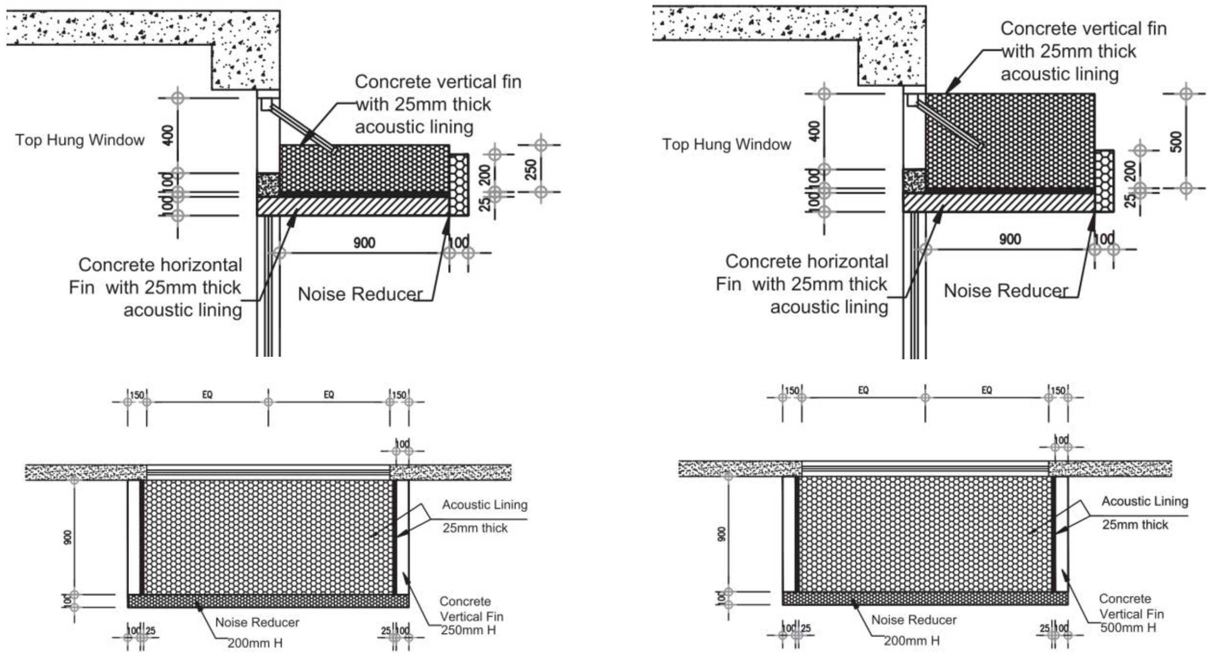
The mock-up room was enclosed with full height drywalls and solid ceiling and floor, with internal and exterior wall finishing as similar as possible to the future development. The construction and internal features of the mock-up room is similar to that of case 1, where the drywalls were constructed to achieve overall sound transmission class of at least STC43.

2.2.1 Enhanced High Level Top Hung Window

Enhanced High level Top-Hung Windows constructed with horizontal/ vertical fins were installed in the mock-up unit to analyse the noise reduction performance under different scenarios summarized in Table 2. Typical sections of the window design are illustrated in Figure 5.

Table 2: Summary of Testing Scenarios for Enhanced High Level Top-Hung Windows (case 2)

Scenarios	Descriptions
1	1. High Level Top-Hung Window 2. Window Opening of 1200mm(L) x 400mm(H) 3. 200mm upright noise reducer at front 4. 1000 mm horizontal fin 5. 250mm vertical fins 6. 25mm internal acoustic lining
2	1. High Level Top-Hung Window 2. Window Opening of 1200mm(L) x 400mm(H) 3. 200mm upright noise reducer at front 4. 1000 mm horizontal fin 5. 500mm vertical fins 6. 25mm internal acoustic lining



SCENARIO 1 SCENARIO 2

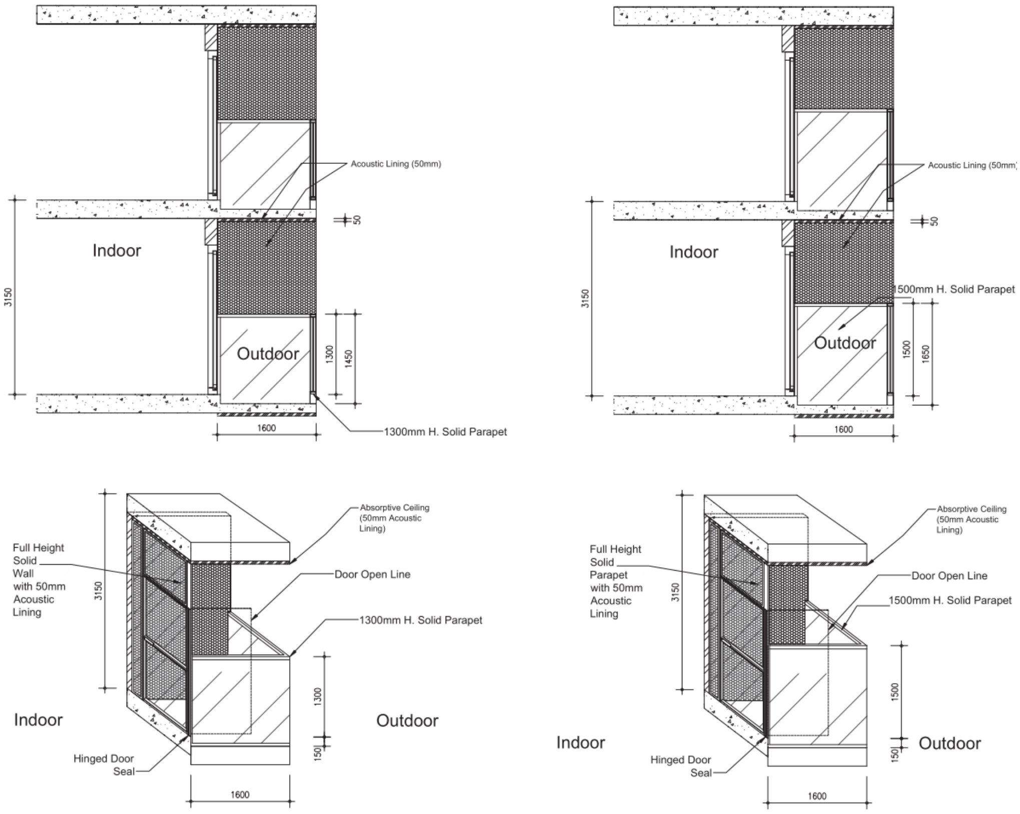
Source (Author, 2019)
Figure 5: Typical Sections & Layouts of Enhanced High Level Top-Hung Window (case 2)

2.2.2 Enhanced Acoustic Balcony

Enhanced Acoustic Balcony constructed with vertical fins and solid parapet were installed in the mock-up unit to analysis the noise reduction performance under different scenarios summarized in Table 3. Typical sections of the window design are illustrated in Figure 6.

Table 3: Summary of Testing Scenarios for Enhanced Acoustic Balcony (case 2)

Scenarios	Descriptions
1	1. 1.6m depth balcony 2. Door Opening of 750mm(L) x 2100mm(H) 3. Full height vertical fin with 50mm sound absorptive lining 4. Ceiling with 50mm sound absorptive lining 5. 1300mm solid parapet (above noise sensitive receiver finish floor level) 6. Sealed hinge door, swinging opposite to the full height wall
2	1. 1.6m depth balcony 2. Door Opening of 750mm(L) x 2100mm(H) 3. Full height vertical fin with 50mm sound absorptive lining 4. Ceiling with 50mm sound absorptive lining 5. 1500mm solid parapet (above noise sensitive receiver finish floor level) 6. Sealed hinge door, swinging opposite to the full height wall



SCENARIO 1 SCENARIO 2

Source (Author, 2019)

Figure 6: Typical Sections and Illustrations of Enhanced Acoustic Balcony (case 2)

3 MEASUREMENT AND CALCULATION

3.1 Simulated Traffic Noise Source

Global road traffic method is adopted to estimate the outdoor/indoor sound level difference with reference to BS EN ISO 140-5: 1998(E) and BS EN ISO 16283-3:2016(E). The Standards state that loud speaker shall be used as an artificial sound source. In the experimental set up, eleven loudspeakers with white noise were used to simulate the line source from outdoor traffic, and the separation distance between speakers was set to 3m with a total length of approximately 30m for the noise source. The standard also suggest the loudspeakers shall be placed with an angle of incidence of 45 degrees.

The sound field generated shall be steady and have a continuous spectrum in the frequency range considered. Therefore, the artificial sound source was corrected to a standardized traffic noise according to the spectrum provided in BS EN 1793-3.

Background noise level at both outdoor and indoor locations will be measured before testing. For all relevant frequency bands, the sound power level of the sound source shall be high enough to give a sound pressure level in the receiving room that exceeds the background noise level by at least 10dB to ensure noise contribution is mainly from the testing signal.

3.2 Testing Angle

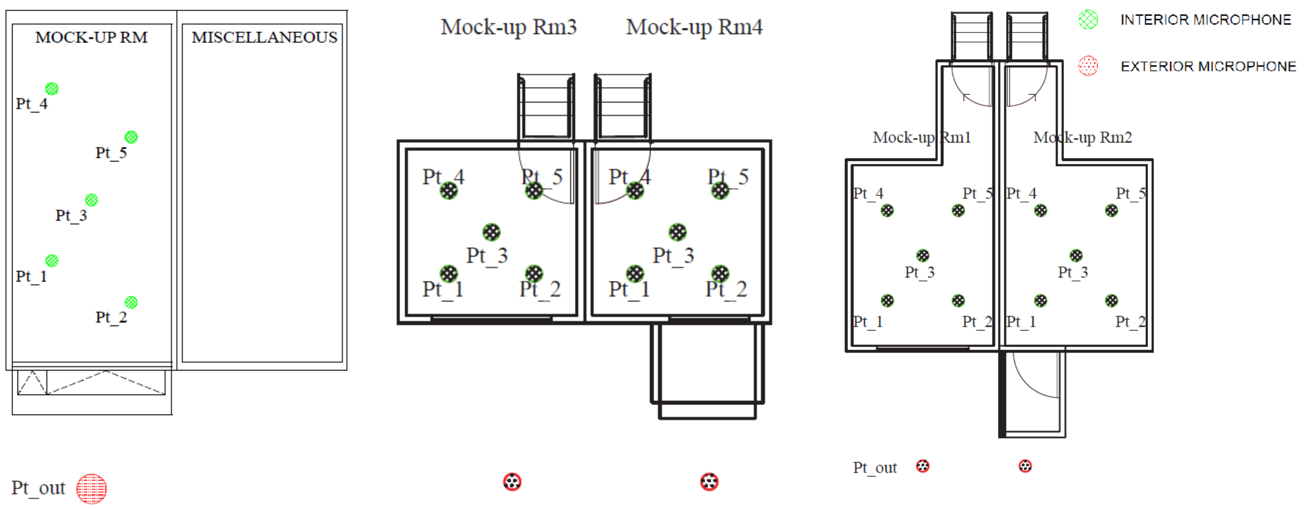
As mentioned above, although the suggested incident angle for the loudspeakers shall be 45 degrees, the performance of the innovative noise reduction windows and balcony in a high rise building would subject to various angles of incidence on different floor levels. In this situation, the critical angles of incidence are the angles to the lowest noise sensitive receivers. The loudspeakers were therefore adjusted to the angles of incidence provided in Table 4.

Table 4: Summary of Angles of Incidence for Loud Speakers

Cases	Noise Mitigation Measures	Angles of Incidence
1	High Level Top-Hung Window	20 degrees
2	High Level Top-Hung Window	18 degrees
	Enhanced Acoustic Balcony	18 degrees

3.3 Measure Procedure

Measurements were made with reference to procedures stipulated in ISO 140-5: 1998(E) and ISO 16283-3:2016(E). The noise level that should be generated by the loudspeakers with reference to the measured background noise level, at least 10 dB higher than the background noise level. Noise measurement was taken simultaneously for both outside and inside of each of the receiving rooms. 5 microphone positions were used to obtain the average sound pressure. Since the simulated noise generated by loudspeaker was a steady source, sampling time of 1 minute at each 5 positions at each room was considered to be sufficient to minimize the measurement variables, uncertainties and errors. Figure 5 illustrates the setup of microphone positions in the mock-up testing.



Case 1
High Level Top-Hung Window

Case 2
High Level Top-Hung Window

Case 2
Enhanced Acoustic Balcony

Source (Author, 2019)
Figure 5: Setup of Microphone Positions in Case 1 and Case 2 Mock-up Testing

3.4 Calculation of Noise Reduction

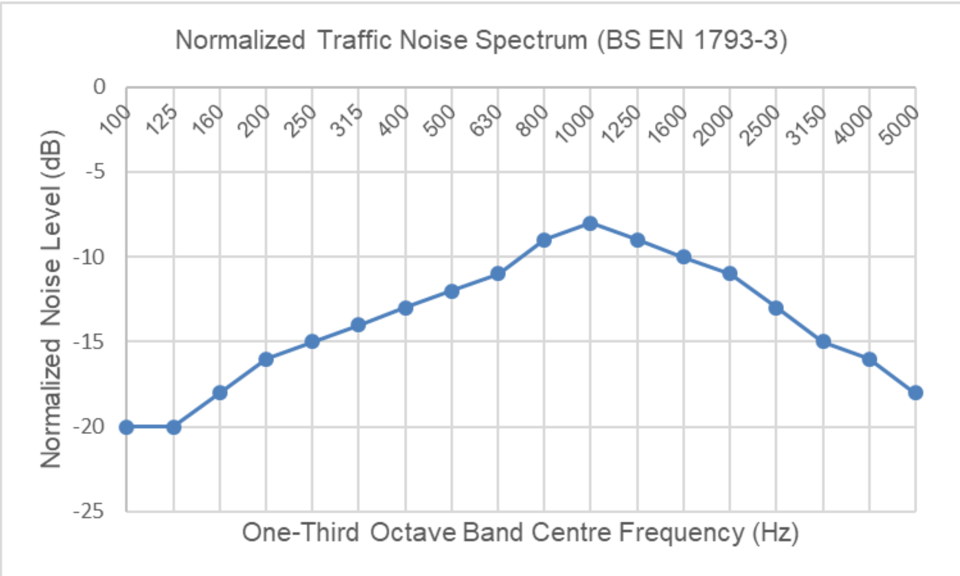
The global road traffic method was adopted in order to evaluate the performance of a whole façade under different test scenarios including all flanking paths. Both indoor and outdoor noise levels for each of the option were measured in 1/3 octave bands with centre frequencies from at least 100Hz to 5000Hz. Standardized level difference was reported for each of the 1/3 octave band.

$$D_{2m,nT} = D_{2m} + 10lg\frac{T}{T_0} \quad (1)$$

where

D_{2m}	$= L_{1,2m} - L_2$
$L_{1,2m}$	= average outdoor sound pressure level at 2m in front of façade
L_2	= energy-average sound pressure level in receiver room
T	= measured reverberation time in receiver room
T_0	= 0.5s, reference value of reverberation time

A single number rating to indicate the traffic noise reduction were determined according to the normalized traffic noise spectrum defined in BS EN 1793-3. Figure 6 illustrates the normalized noise spectrum adopted in the calculation.



Source (BS EN 1793-3)
Figure 6: Normalized Traffic Noise Spectrum (BS EN 1793-3)

4 RESULTS AND DISCUSSIONS

4.1 Mock-up Results of High Level Top-Hung Window (case 1)

The testing results of the High Level Top-Hung Window under different scenarios is summarized in Table 5. The additional traffic noise reduction is defined to be compared with a conventional high level top-hung window without noise mitigation measures; having 9.1 dB(A) of indoor-outdoor noise reduction.

Table 5: Summary of Testing Results for High Level Top-Hung Window (case 1)

Scenarios	Noise Mitigation Measures	Additional Traffic Noise Reduction dB(A)
1	High Level Top-Hung Window (case 1)	6.6
2		6.6
3		5.7
4		4.7

The only difference between scenario 1 and scenario 2 is that MPA was installed in Scenario 1 but not in scenario 2. According to the results, the additional traffic noise reduction were both 6.6dB(A), which implied that the performance efficiency for the MPA could be considered as negligible under a narrow incident angle of loud speakers.

In scenario 3 and 4, the vertical fins were removed and the horizontal fin were shortened from 750mm to 650mm and 550mm respectively. According to the results, the additional traffic noise reductions were reduced to 5.7dB(A) and 4.7dB(A) which could still provide an acceptable traffic noise reduction.

4.2 Mock-up Results of Enhanced High Level Top-Hung Window (case 2)

The testing results of the Enhanced High Level Top-Hung Window under different scenarios is summarized in Table 6. The additional traffic noise reduction is defined by comparison with a conventional high level top-hung window without noise mitigation measures; having 8.0 dB(A) of indoor-outdoor noise reduction

Table 6: Summary of Testing Results for Enhanced High Level Top-Hung Window (case 2)

Scenarios	Noise Mitigation Measures	Additional Traffic Noise Reduction dB(A)
1	Enhanced High Level Top-Hung Window (Case 2)	8.2
2		9.9

According to the testing results, the Enhanced High Level Top-Hung Window can achieve a significant additional traffic noise reduction performance ranging from 8.2 dB(A) to 9.9 dB(A). Comparing to the configuration in between scenario 1 and scenario 2, the vertical fins in scenario 2 are 500mm which are 250mm greater than that in scenario 1.

The larger vertical fins in scenario 2 achieved an addition of 1.7dB(A) traffic noise reduction. Hence, it is shown that vertical fins can further enhance the traffic noise reduction performance.

4.3 Mock-up Results of Enhanced Acoustic Balcony (case 2)

The testing results of the Enhanced Acoustic Balcony under different scenarios is summarized in Table 7. The additional traffic noise reduction is defined by comparison with a conventional high level top-hung window without noise mitigation measures; having 8.0 dB(A) of indoor-outdoor noise reduction

Table 7: Summary of Testing Results for Enhanced Acoustic Balcony (case 2)

Scenarios	Noise Mitigation Measures	Additional Traffic Noise Reduction dB(A)
1	Enhanced Acoustic Balcony (Case 2)	7.8
2		9.7

According to the testing results, the Enhanced Acoustic Balcony can achieve a significant additional traffic noise reduction performance ranging from 7.8 dB(A) to 9.7 dB(A). The difference between the configurations in scenario

1 and scenario 2 is the height of the solid parapet. The solid parapet in scenario 2 is 1500mm which is 200mm greater than that in scenario 1.

The larger solid parapet in scenario 2 achieved an addition of 1.7dB(A) traffic noise reduction. Hence, it is shown that a solid parapet can further enhance the traffic noise reduction performance.

5 CONCLUSION

Full scale mock-up measurements were carried out in the present study to investigate the traffic noise reduction performance of different designs of High Level Top-Hung Window and Acoustic Balcony in terms of traffic noise reduction from the outdoor into indoor while maintaining adequate openings for natural ventilation. The benefits of sound absorptive materials, horizontal/ vertical fins and solid parapet were also investigated.

In case 1, the testing results show that the High Level Top-Hung Window can achieve an additional traffic noise reduction ranging from 4.7 dB(A) to 6.6 dB(A). The performance efficiency for the MPA at the top-hung window pane could be considered as negligible under a narrow incident angle of loud speakers.

In case 2, the testing results show that the Enhanced High Level Top-Hung Window can achieve a significant additional traffic noise reduction ranging from 8.2 dB(A) to 9.9 dB(A), whereas the Enhanced Acoustic Balcony can achieve a significant additional traffic noise reduction performance ranging from 7.8 dB(A) to 9.7 dB(A). Vertical fins at Enhanced High Level Top-Hung Window; and solid parapet at Enhanced Acoustic Balcony can be enlarged to further enhance traffic noise reduction performance of these devices.

REFERENCES

Xiang YU, Li CHEUNG, Yuhui Tong, Jie Pan. 2014 ‘Sound attenuation using duct silencers with micro-perforated panel absorbers’. Inter.noise 2014