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APPLICATION OF ACOUSTIC WINDOW AND ACOUSTIC BALCONY FOR PUBLIC HOUSING DEVELOPMENT IN HONG KONG

ABSTRACT

Hong Kong is a congested city with limited flat land areas for residential purposes. Many high-rise residential buildings, especially those within the urban districts, are therefore located near to very busy trunk roads with severe traffic noise impact. Embracing a caring attitude to create a healthy living environment to our residents in public housing estates, the Hong Kong Housing Authority (HKHA) have strived in the past to tackle noise issue in public housing sites and applied a host of noise mitigation measures including noise enclosures/barriers, building setback, etc. to reduce the impact and nuisance.

With more housing sites having excessive noise issue, more innovative and cost effective noise mitigating design at building façade envelope becomes essential. In this paper, we share our experience in the research and development of innovative building façade noise mitigating designs by making reference to some public housing developments in Hong Kong. We also give an account on how the noise challenges are tackled in recent projects by making use of acoustic window and acoustic balcony design.

Keywords: Public Housing, Noise Mitigation Measures, Acoustic Window, Acoustic Balcony

INTRODUCTION

The Hong Kong Housing Authority

Established in 1973 under the Housing Ordinance, the HKHA develops and implements one of the largest public housing programme in the World, providing affordable public housing in meeting the need of about 30% of the Hong Kong population. According to the latest update of the Long Term Housing Strategy first released in December 2014, the Hong Kong SAR Government has updated the projection of housing demand for the 10-year period from 2016/17 to 2025/26 ranges from 395,600 to 477,400 units, and 60% of which (i.e. about 280,000) is the target supply on the public housing. With the mission to building more flats in scarce land resource, the HKHA, being the developer, aims to secure a healthy and comfortable living environment in our public housing developments.

Planning and Design against Noise Impact

In Hong Kong, Noise Control Ordinance Cap. 400 (NCO) [6] and Hong Kong Planning Standards & Guidelines (HKPSG)[5]) provide the criteria of planning and design of development with respect to noise issue. Environmental Assessment Study Report (EAS) needs to be submitted to Environmental Protection Department (EPD) to demonstrate effective noise mitigation measures to be incorporated in the design of new public housing developments to comply with the relevant criteria, especially for sites requiring rezoning to residential use.

Different design considerations are sometimes conflicting requirements such as natural ventilation and noise insulation at building envelope. An optimum building design for human comfort and hygiene, in particular for a site subject to significant noise impact, is not simply the provision of noise mitigation measures, but rather the balancing of such measures against other needs and constraints such as natural ventilation and lighting. While the provision of noise mitigation measures at building envelope might well attenuate the noise level of the flats, they may adversely affect the ventilation performance inside the domestic units required under the Buildings Ordinance[7]. It becomes a challenge for the designers to address these paradoxically conflicting requirements that are difficult to meet at the same time, but the satisfactory resolution of noise issues, when balanced against other needs and constraints will fosters an environmental friendly living environment conducive to healthy living. Building smart and energy efficient buildings without compromising our flat production target has been our drive for Research & Development of innovative design.

In our completed public housing developments, we have applied various passive design measures to mitigate noise impact and meet the requirements of relevant ordinances and guidelines, as well as to fulfil the statutory requirements in other competing environmental aspects. These measures include single-aspect design, optimized block disposition, architectural fins, noise barriers, and using non-noise sensitive podiums and buildings such as multi-storey car parks or retail facilities as noise buffers (Figure 1).

Figure 1: Non-noise Sensitive Buildings for Screening Off Road Traffic Noise

While each measure has its own merits and demerits, site constraints often restrict their full application, and more innovative measures are required at particularly difficult sites. In recent years, we have carried out research and development on innovative mitigation measures and explored these measures under a collaborative approach with our stakeholders in resolving the noise issues in our developments.

INNOVATIVE MITIGATION MEASURES

The innovative measures recently developed for mitigating road traffic noise have been incorporated at the receiver end of the building blocks which are under better control and implementation in the housing developments. These measures have optimized the site development potential of our developments and improve the living environment of the residents. The innovative measures are described in details as follows:

Acoustic Window[1][2][4]

For San Po Kong public housing development which abuts heavily trafficked Prince Edward Road East, the unmitigated noise level at the site was anticipated at an excessive level of 85 dB(A). Conventional mitigation measures including set-back, building block orientation, noise fin at building block and low noise road surfacing could only contribute noise reduction up to about 7 dB(A). Innovative measures have to be explored to further attenuate 8 dB(A) in order to meet the 70 dB(A) noise standard for all residential flats, which was also a rezoning requirement for this development. Hence, we collaborated with Environmental Protection Department (EPD) and the Hong Kong Polytechnic University (HKPolyU) to form a Research Team to work out the design of acoustic window, which would function as a modified double-glazed window with offset openings to allow natural ventilation (Figure 2).

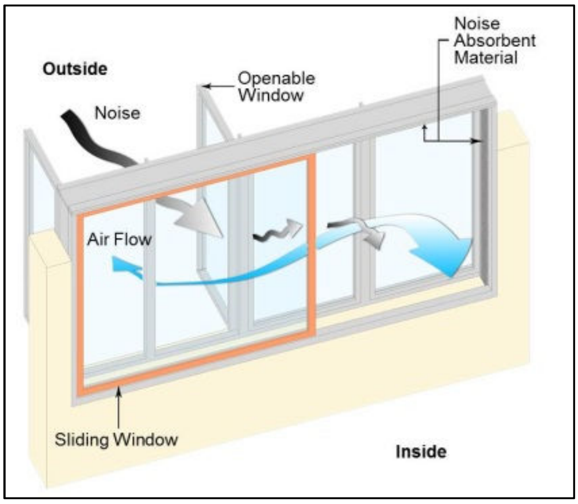


Figure 2: Configuration of Acoustic Window System

In mid 2009, we commenced our exploration by conducting laboratory tests on this window design concept with various window configurations (Figure 3), noise source orientation, use of sound absorption material in the window system (Figure 4), etc. to verify feasibility and the order of noise attenuation performance of the design.


Figure 3: Laboratory Testing of Different Acoustic Window Configurations


Figure 4: Laboratory Testing Scenarios: Sound Absorption Material on 4 Sides (Left) and Micro Perforated Absorber onto Panes (Right)

Figure 5 illustrates the setup of the laboratory noise measurement. Noise measurements were carried out at chambers with the acoustic windows and also at control unit with conventional openable window. In both cases, the noise levels at the source room and receiver room were measured and compared to ascertain the insertion loss of the windows. The noise attenuation effect of the acoustic window over conventional window was defined as the excess of insertion loss of acoustic window over conventional window.

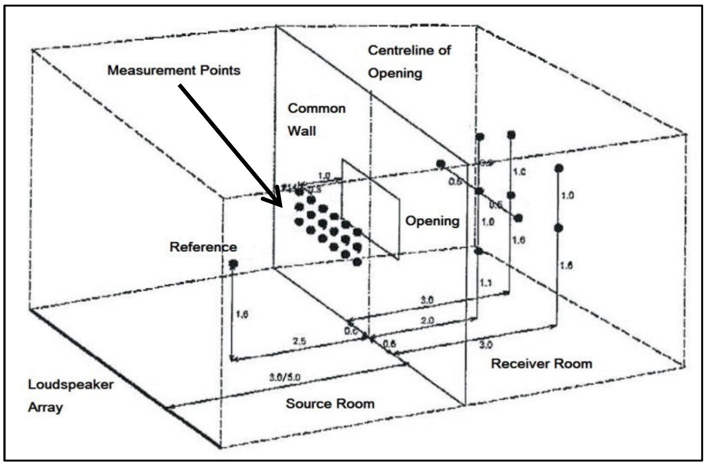


Figure 5: Setup of Laboratory Noise Measurement

The results of the laboratory testing demonstrated the feasibility of the acoustic window design to provide the essential noise mitigation effect required by the San Po Kong project. Moreover, the noise measurement results in the laboratory tests for different window configurations such as gap width between window panes, overlapping of outer and inner window panes, use of noise absorbent materials at the window frame etc. provide very useful information for further design and development of the details of the acoustic window.

Based on the laboratory measurement findings, active deliberation among HKHA's project team, EPD and HKPolyU's expert were concentrated on further design of the acoustic window for application in the development as well as detailed evaluation of sound attenuation of the actual design. It was considered that the effective sound attenuation of the acoustic window should be established by direct comparison of its performance against that of conventional window under in-situ noise environment. Full scale mock-up flats installed with prototype acoustic window was subsequently set up at San Po Kong site to facilitate in-situ acoustic measurements (Figure 6). The site mock up consisted of two identical side-by-side modular flats. The mockup was located close to the noise source, Prince Edward Road East. As shown in the photo of Figure 6, the right-hand-side flat was equipped with the conventional side-hung window while the left-hand-side flat was equipped with the acoustic window.

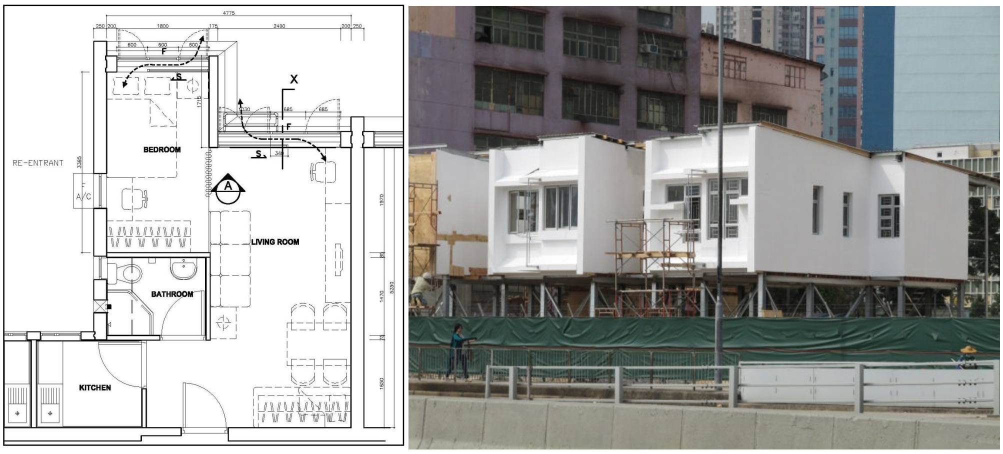


Figure 6: Mock-up Flats for Comparison of the Performance of Conventional Window and Acoustic Window

The noise levels inside each test flat were measured by 6 microphones spaced inside with at least 1m away from walls and floor. Three exterior microphones were located at 1m away from the mockup façade outside each window opening to measure the incident noise levels. Figure 7 shows the setup of the microphone arrays. A total of 34 nos. of microphones were employed to measure simultaneously the exterior and interior noise levels of the mock-up flats under 20 flat/window scenarios during peak hours of traffic.

Figure 7: Microphones setup (left: façade; right: indoor)

Upon testing for different scenarios, it was established that the acoustic window with noise absorption materials at the window frame could achieve noise attenuation up to about 8 dB(A). With the employment of acoustic window system, 100% predicted noise compliance with the noise standard can be achieved to enable the San Po Kong project to proceed. Besides meeting the noise requirement, compliance of the window design under the Buildings Ordinance is equally necessary to ensure the performance of ventilation and lighting for the flats. Upon completion of the project, further noise monitoring would be arranged in completed flat for verification. During the design process, other operational factors like window cleansing, clothes hanging and long term maintenance have been carefully considered from the residents' perspectives.

Acoustic Balcony (Arc-Screen to First Generation) [3][4]

Wing Cheong Estate development in Sham Shui Po is exposed to severe road traffic noise impact due to the heavy traffic at the West Kowloon Corridor at some 35m away from the site. In order to provide some self-screening effect against noise impact, Y-shaped block design was adopted for reducing the view angle from the concerned flats to the elevated West Kowloon Corridor. However, initial road traffic noise assessment indicated that the flat would still be subject to a maximum noise level of 78 dB(A) against the required standard of 70 dB(A) for residential flats. Since the site and road configuration rendered conventional noise measures (such as building setback, on-site noise barrier, etc.) impractical, the project team came up with an innovative arc-screen design concept for shielding noise impact in front of the windows.

Desktop numerical analysis was first conducted to explore the feasibility of the measure. Ray tracing computer simulations for acoustic model were carried out to estimate the effectiveness of the arc-screen design concept (Figure 8).

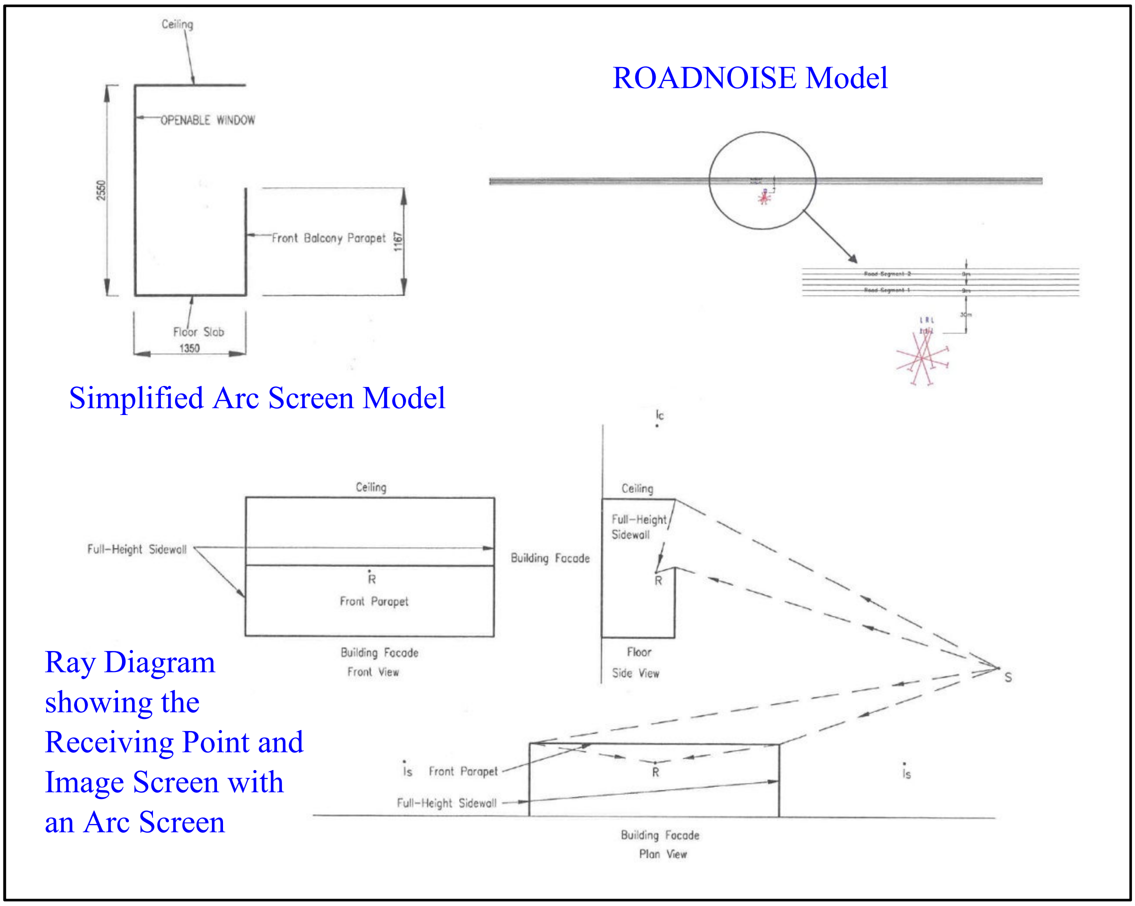


Figure 8: Ray Tracing Simulations Model

Affirmative findings were demonstrated by the ray tracing simulation. After reviewing the simulation findings with EPD, it was considered necessary to verify the effectiveness of the measure and evaluate its in-situ noise reduction effect by on site measurement using prototype installation.

In mid 2008, the project team proceeded with a 3-storey full scale model prototype installation at Dongguan in Mainland China, simulating the development's configuration for in-situ noise measurements. Various arc-screen options with different materials (incl. concrete parapet, polymethyl methacrylate (PMMA) parapet, etc.) have been worked out for testing (Figure 9).

Figure 9: Site Mock-up Model at Dongguan and Measurement Scenarios

Loudspeaker arrays were installed at the site mock up to simulate the line source of road traffic. Test scenarios with loudspeaker arrays at different offset distance representing different inclination angle of noise source were included in the site measurement to simulate the flats at various floor levels (Figure 10). The loudspeakers were set at such inclination that their normal axes were pointing towards the window and the balcony during each measurement.

Figure 10: Loudspeaker Arrays

Three microphones were located at 1m away from the mock-up façade outside/ inside each window opening to capture the incident noise levels. Figure 11 shows the setup of these microphone arrays in the study. A total of about ten thousand acoustic measurements have been taken in the Donguan model. Results of the mock-up testing further demonstrated and verified the effectiveness of noise attenuation by the arc screen.


Figure 11: Microphones Setup (left: façade; right: indoor)

Upon further consultation with various stakeholders, this arc-screen design concept finally evolved in the form of an acoustic balcony for use in the project, as shown in Figure 12, which comprises the features of a balcony parapet, a inclined glass panel, extended side walls and noise absorptive linings at the side walls and ceiling of the balcony.

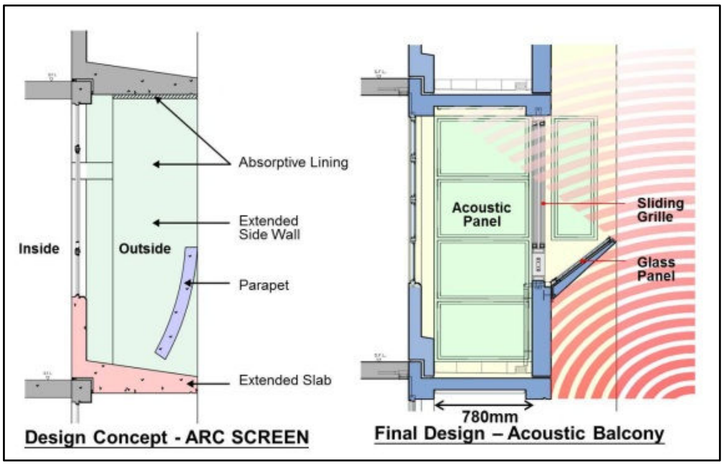


Figure 12: Initial Arc Screen Design Concept and First Generation of Acoustic Balcony Design

Together with the application of noise absorptive linings, the Acoustic Balcony could achieve maximum noise reduction up to 6.4 dB(A). After completion of the building works in July 2013, on-site noise verification has been conducted (Figure 13). Selected completed flat facing the noisy West Kowloon Corridor was adopted for verification. Microphones were installed at both the interior and exterior (1m from window panel) of the flat to measure the indoor noise levels and that at the noise sensitive receiver location. Blank façade noise levels were taken at another flat above the 'case flat' to represent the base case scenario. In summary, the verification on-site measurement confirmed that the predicted noise reduction could be achieved.

Figure 13: On-site Noise Verification

Use of Acoustic Balcony has enabled the Wing Cheong Estate development to proceed amidst the severe noise impact. Consideration has been given to facilitate associated daily operation such as clothes hanging and window cleansing as well as long term maintenance. According to the resident survey taken after its occupation in 2013, this Acoustic Balcony design which could effectively reduce noise by about 2 to 6 dB(A) were much to the satisfaction of the tenants (Figure 14).

Figure 14: Acoustic Balcony Flat

Acoustic Balcony (Enhanced Design)

Notwithstanding the success of the innovative Acoustic Window and Acoustic Balcony (First Generation), we strived to explore a balcony design with even more effective noise attenuation performance. We contemplated an enhanced Acoustic Balcony design (Figure 15), which amalgamates the Acoustic Window concept in the first generation of Acoustic Balcony and could allow the ventilation path at more decent width than the Acoustic Window. To ameliorate the incidence of noise through the balcony door into the flat, a sliding screen is installed in front of the balcony door in the balcony. Other auxiliary feature like noise absorptive material at the wall and ceiling of the balcony and inclined projecting panel from the parapet would be provided on a site-specific basis for further noise mitigation enhancement. Apart from the noise aspect, other factors such as natural ventilation have to be carefully considered in the enhanced version.

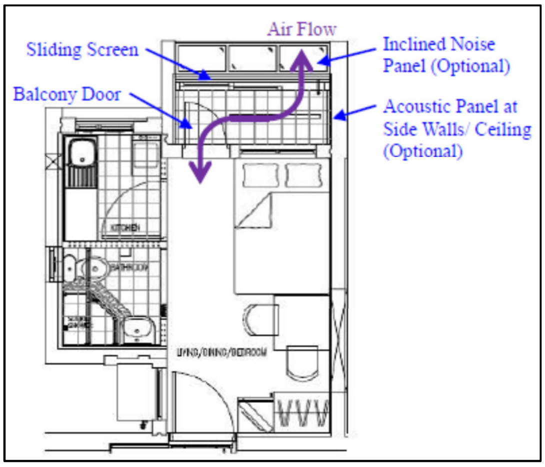


Figure 15: Layout of Enhanced Acoustic Balcony Design

Following similar approach as in the development of previous innovative measures, it was agreed among the project team, EPD and HKPolyU's experts that the effective noise attenuation of the enhanced Acoustic Balcony would be established by comparison of its performance against that of conventional window under in-situ noise environment. In July 2015, we set up full-scale mock-up flats for the test case unit with prototype acoustic balconies and the control case unit with conventional window inside an existing vacant school building at Yue Wan Estate to verify the effectiveness of the noise reduction effect by in-situ acoustic measurements (Figure 16). The mock-up site was located near to Wing Tai Road, which is a busy District Distributor road. Initial road traffic noise assessment indicated that the unmitigated case would achieve a maximum noise level of 79 dB(A). The mock up site with the disused school building would be developed for a public rental housing development providing some 800 flats by 2019/2020. This housing development is the first pilot project adopting the enhanced Acoustic Balcony design.

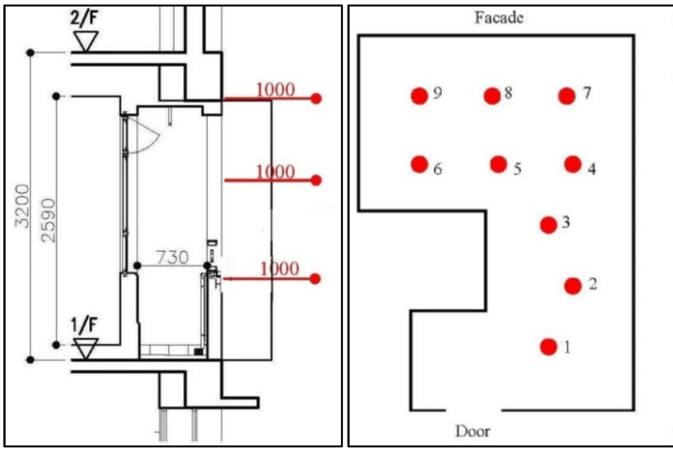
Figure 16: Mock-up Flats for Comparison of the Performance of Enhanced Acoustic Balcony and Conventional Window

As shown in Figure 16, the left-hand side flat was equipped with the conventional side-hung type openable windows while the right-and side flat was fitted with the enhanced Acoustic Balcony. The interior mock-up was made of layers of plywood boards. During measurement, the test flats were concealed acoustically to avoid any noise break-in into the mock-up flats.

Both in-situ traffic noise source and loudspeaker noise source had been used for the measurements. Traffic on Wing Tai Road was used as a noise source and the corresponding measurements were carried out during the peak hours of traffic flow. However, the incident angle of Wing Tai Road was small and the measurement could only represent the scenario for the flats at the lower levels. To simulate the flats at various higher levels, loudspeaker arrays at different offset distance representing different inclination angle (15^{o}, 30^{o}, 45^{o}, 60^{o}) of noise source were employed (Figure 17). The loudspeakers were set at such inclination that their normal axes were pointing towards the window and the balcony during each measurement. Facade noise levels from loudspeakers were kept at around 90 dB(A) (as the dominant noise source) during the measurements.

Figure 17: Loudspeaker Arrays

The noise levels inside each test flat were measured by nine microphones randomly spaced inside the flat, but at least at 1m away from walls and floor. These microphones spanned over the living volume of the flat. Three microphones were located at 1m away from the mock-up façade outside each window opening to capture the incident noise levels as well as to provide correction of incident sound intensity differences. Figure 18 shows the setup of these microphone arrays in the present study. The conventional window opening size was kept at that of minimum required area for ventilation (i.e. 1/16 of floor area as prescribed window area for ventilation). At least 20 microphones were involved to measure simultaneously the exterior and interior noise levels of the mock-up flats under 23 scenarios of different flat/enhanced balcony settings, i.e. with and without noise absorptive material at the wall and ceiling of the balcony and/or inclined projecting panel from the parapet. The difference between the average noise levels inside the control flat and enhanced Acoustic Balcony flat represents the noise attenuation of the enhanced Acoustic Balcony after the application of traffic noise weighting.



Point	Distance in metres from Inner window pane	Side wall	Floor
1	5.12	1.4, right-hand-side wall	1.45
2	4.12	1.0, right-hand-side wall	1.30
3	3.12	1.4, right-hand-side wall	1.65
4	2.12	1.0, right-hand-side wall	1.20
5	2.12	2.3, left-hand-side wall	1.00
6	2.12	1.0, left-hand-side wall	1.65
7	1.0	1.1, right-hand-side wall	1.40
8	1.1	2.2, left-hand-side wall	1.60
9	1.0	1.0, left-hand-side wall	1.20

Figure 18: Microphones setup (left: façade; right: indoor)

Upon testing for different flats and enhanced balcony scenarios, it was established that, the enhanced Acoustic Balcony with the fittings as stated above could achieve relative noise attenuation up to around 10 dB(A), which was even higher than Acoustic Window and the first generation of Acoustic Balcony. It would be an effective design for noise mitigation whilst at the same time allow desirable natural air ventilation for the habitable area of the flat. Similar to the first generation of Acoustic Balcony, during the design process, other operational factors in the use of this balcony system like cleansing, clothes hanging installations and long term maintenance have to be carefully considered. At the moment, we are refining the design to meet other aspects like buildability and other balcony orientation with respect to road alignment. But this noise mitigation design feature is now being adopted in some of our housing projects with acute noise issue including Wing Tai Road project.

In fact, the recently completed Wah Ha Estate in Chai Wan is the fore-runner of enhanced acoustic balcony design. Built in 1959, the 6-storey factory building which is the last H-shape factory building in Hong Kong and has been graded as a historical building in 2013 is adaptive reused as residential block (Figure 19). In order to retain the heritage value of the building, the existing building fabric, including its structure and layout, was kept as far as possible.

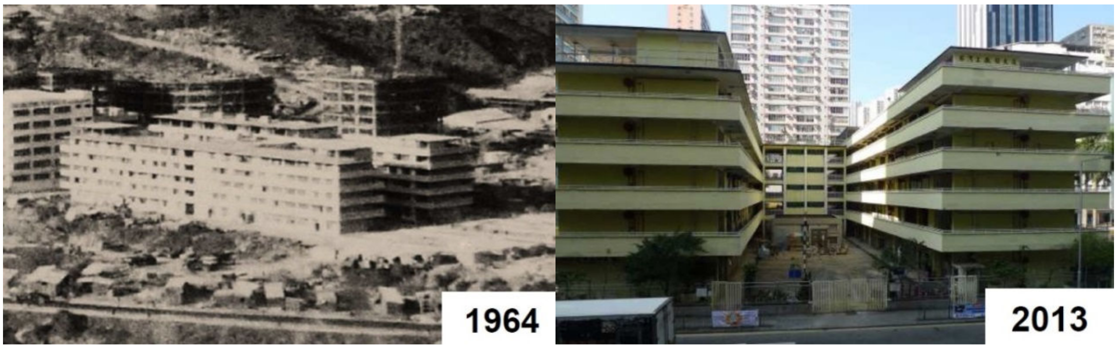


Figure 19: Chai Wan Factory Building

In order to mitigate the operation noise from the nearby railway, the previous corridor of the factory building is modified as the acoustic balconies for the domestic units. Acoustic panels with low-frequency sound absorption materials were installed at the internal walls and ceilings of the balcony to enhance noise attenuation whereas light transparent noise panels were installed on top of the parapet of the acoustic balcony to increase the acoustic path from the noise source to the receivers (Figure 20). Upon completion of the building works in 2016, on-site noise verification has been conducted, confirming adequate noise reduction could be achieved.

Figure 20: Acoustic Balcony Flat in Wah Ha Estate

COLLARBORATION WITH EPD AND OTHER STAKEHOLDERS

In order to achieve success in innovation with breakthrough in research & development, we work and engage with the regulators as well as practitioners and academics. Over the years, HKHA have been working in close collaboration with EPD, Buildings Department, HKHA's Independent Checking Unit and other stakeholders of expertise such as environmental consultants and tertiary educational institutes in the exploration of various innovative measures to mitigate noise impact to our public housing developments. During the research and development of Acoustic Window and Acoustic Balcony, EPD gave valuable advice on the knowledge and experience in similar research projects together with the regulatory requirements of noise control whereas the environmental consultants and tertiary educational institutes were capable of providing acoustic expertise in the investigation and testing. HKHA being the project proponent are better familiarised with the design, construction and operation aspects and have undertaken the project manager and designer roles of these innovation projects. Experience indicates that collaboration approach with other stakeholders is essential and practicable to develop innovative measures for the benefit of the community. HKHA welcome collaboration with other stakeholders of construction industry (Figure 21) to explore innovations and to share and exchange the experience gained during the research and development processes.

Figure 21: Visit to Completed Wah Ha Estate by Stakeholder in Jul 2016

CONCLUSION

The HKHA's mission is to implement the public housing programme in meeting the housing needs of those who cannot afford private housing in Hong Kong in support of the Government policy on housing. Yet land has always been a precious and indispensable ingredient in HK's housing, economic and social development. Owing to the limited land supply, we need to make the best use of every piece of land, optimise the development potential and provide as many domestic flats as practicable within the shortest possible time. All the mitigation measures discussed above will enable us to build more in areas with undesirable noise environment, without compromising the environmental quality of housing estates.

Gaining from past experience, through the development of various innovative noise mitigation designs and measures, we have optimised the development potential of several difficult public housing sites, and holistically improved the environmental quality of these estates at the same time. Looking ahead, we will continue to grow and mature, in face of challenges and innovation. We excel through a people-centric approach, applying our core values of the 4Cs (Caring, Customer Focused, Creative and Committed) plus holistic Total Quality Management to build sustainable communities in a high density urban environment.

Reference

[1] S.K. Tang, Y.G. Tong and others. 'On site performances of ventilation windows for public housing development', paper presented at the Acoustics 2012, Hong Kong.

[2] Yeung, M., Ng, I., Lan, J., Tang, S. K., Lo, D. and Yeung, D., 'Tackling Traffic Noise through Plenum Windows – An Application in Hong Kong', Proceedings of the 43rd International Congress and Exposition on Noise Control Engineering, Melbourne Australia, 16-19 November 2014.

[3] Kan, J., Chan, I., Ng, I., Yeung, M., Tang, S. K. and Lo, P., 'Study of Noise Reduction Effect of Acoustic Balconies in High-rise Building', Proceedings of the 44th International Congress and Exposition on Noise Control Engineering, San Francisco, California, U.S.A., 9-12 August 2015.

[4] KK Lau, Isaac Chan, Maurice Yeung, John Ho, Stephen Yim. 'Noise Planning in Public Housing Development in Hong Kong', paper presented at the 23rd International Congress on Sound & Vibration, Athens, Greece, 10-14 July 2016.

[5] 'Hong Kong Planning Standards and Guidelines (HKPSG)' published by Planning Department, HKSAR.

[6] 'Noise Control Ordinance - Chapter 400' published by HKSAR.

[7] 'Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers APP-130, Lighting and Ventilation Requirements – Performance-based Approach' published by Buildings Department, HKSAR.