Research and Development of Noise Mitigation Measures for Public Housing Development in Hong Kong – A Case Study of Acoustic Balcony

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ABSTRACT
Hong Kong is renowned for its high density living environment. With limited land sources, residential developments, including public housing developments, may be located in close proximity to heavily trafficked roads or other noise sources. Embracing a caring attitude to create a healthy living environment to our residents in public housing estates, the Hong Kong Housing Authority (HKHA) have applied a host of noise mitigation measures to reduce the impact and nuisance. Depending on the site environment, the mitigation measures can be applied at source, at propagation path and/or at receiver end. Apart from these measures, with more housing sites having severe noise issue, more innovative building design in a cost effective manner becomes essential. This paper shall highlight our recent research and development of innovative building designs on noise mitigation by making reference to some public housing developments in Hong Kong. A detailed case study will be presented holistically on the evolution of the acoustic balcony from its conceptual arc-screen form to the first generation of acoustic balcony and lately to an enhanced configuration to tackle the most severe noise challenge without compromising the performance of natural ventilation for the flats.

Keywords: Acoustic Balcony, Arc-screen, Innovative, Noise Mitigation

1. INTRODUCTION
Established in 1973 under the Housing Ordinance, the Hong Kong Housing Authority (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. At the early stage of the project planning cycle, we need to submit Environmental Assessment Study Report (EAS) for the development to demonstrate effective noise mitigation measures in the design of new public housing developments to the satisfaction of Environmental Protection Department (EPD) (i.e. comply with the criteria under the Noise Control Ordinance Cap.400 (NCO) and Hong Kong Planning Standards & Guidelines (HKPSG)), especially for sites requiring rezoning to residential use.

The challenge to achieve an optimum building design, 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. A noise mitigation measures at building envelope might well attenuate the noise level of the flats, but may adversely affect the ventilation performance inside the units required under the Buildings Ordinance. The prescriptive requirements on openable windows to achieve natural lighting and ventilation is stipulated in Building (Planning) Regulations 30 and 31, or otherwise demonstration of achieving the

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minimum ventilation rate of 1.5 air change per hour in accordance with Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers APP-130 issued by Buildings Department (BD). They are paradoxically conflicting requirements that are difficult to meet at the same time. Nevertheless, the satisfactory resolution of noise issues, balanced against other needs and constraints, fosters a harmonious living environment. We wish to build smart and energy efficient buildings without compromising our flat production target. This becomes our driver for Research & Development as well as innovation.

To mitigate noise impact and meet the requirements of relevant ordinances and guidelines, while fulfilling the statutory requirements in other competing environmental aspects, we explore and apply several passive design measures, ranging from 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. While each measure has its own merits and demerits, site constraints often restrict their full application, and more innovative measures are required at particular difficult sites. In recent years, we have carried out research and development on innovative mitigation measures and explored practicable approaches with our stakeholders in resolving the noise issues in our developments.

2. ASSESSMENT CRITERIA AND NOISE CONTROL STANDARD

HKPSG sets out the road traffic noise standards whereas the railway noise and industrial/commercial noise are controlled under the NCO. The noise standards are summarized as follows -

(a) For road traffic noise, the assessment criteria are stipulated in the HKPSG which provides a set of standards applicable to different land uses, with the noise standards for (i) domestic premises, hotels and offices at 70dB(A), (ii) educational institutions at 65db(A) and (iii) hospitals and clinics at 55dB(A);

(b) For railway noise an fixed noise sources from industrial/commercial premises, statutory standards under NCO range from 50dB(A) to 70dB(A), depending on the background noise of the area, the nature of land use in the vicinity and the time period (day, evening or night) under consideration; and

(c) For other specific noise source including bus depots/termini, wholesale markets and container terminals, it is required under HKPSG to consider during planning stage the location of these facilities so that there is no line-of-sight of the noise sources from the noise sensitive receivers or provide screening to the noise sources.

3. GENERAL PRINCIPLE OF NOISE MITIGATION MEASURES

We usually apply a combination of any of the three generic types of noise mitigation measures for the protection of noise sensitive receivers from noise impacts, namely (a) mitigation measures at source, (b) mitigation measures on the path of propagation, and (c) mitigation measures at receivers.

3.1 Mitigation Measures at Source and on Path of Propagation

In general, mitigation at source and mitigation on the path of propagation are the most effective ways of easing noise problem. The choice of mitigation measures at source depends on site constraints and the acoustic performance required for individual housing projects. These may include the use of low noise road surfacing that can reduce noise by up to 3dB(A). Other measures include:

3.1.1 Off-site Noise Barriers for Road/Railway Noise

Off-site noise barriers to mitigate noise impact have been used for many public housing projects. Such barriers take up ground space, especially those with heavy structures, which may pose great constraints in tight sites. A noise barrier reduces noise by interrupting the propagation of sound waves and prevents them from reaching the sensitive receivers. For effectiveness, the barrier should be on the line of sight from the receiver to the noise source, such that the receivers is behind the acoustic “shadow zone” of the noise source. Examples of noise barriers used in recent public housing projects include construction of off-site noise barriers at public road at Tuen Mun Area 54 Site 2, and construction of a trackside noise barrier to abate the railway noise at Tung Chung Area 56 which abuts directly the Tung Chung railway line (Figure 1).
3.1.2 Mitigation Measures at Fixed Noise Source

In order to rezone sites successfully for residential use, fixed noise sources in their proximity, such as mechanical plant, must be properly treated. Acoustic mitigation measures at source are the most effective means to abate fixed plant noise. For example, in the Fo Tan public housing development project, the adjacent commercial building to install acoustic enclosure and louvers to shelter the existing chiller plant and cooling towers at their roof. In the public housing development project at Ex-Kwai Chung Police Married Quarters, we have liaised with Government Departments for the replacement of the existing cooling fans at the police station building adjacent to the development. With their collaboration, the at-source measures would be implemented before the housing development completion.

3.1.3 Noise Cover for Public Transport Interchange (PTI)

A number of our public housing sites are located very close to PTIs. Noise barriers are sometimes ineffective in blocking the line-of-sight to the noise source at the PTI as required by the EPD. Noise cover has to be used instead. To avoid the use of mechanical ventilation and fire services installations which will increase the future maintenance costs, we designed a special cover with appropriate openings and orientation with minimal maintenance requirement for the PTIs at Hung Fuk Estate (Figure 2) and Shui Chuen O Estate.

3.2 Mitigation Measures at Receiver

While noise impact is more effectively mitigated at source, such mitigation measures may not always be practical for reasons such as lack of space for noise barrier erection. Hence, mitigation measures at the receiver end need to be considered to overcome the noise impact. These measures are based on three types of acoustic principles – screening, setback and reducing view angle.

For some specific sites, the building blocks may be designed to set back from noisy roads and disposition at a skewed angle and farthest away from the noise source to reduce the impact on the building façade. Sometimes, vertical fin walls may also be added adjacent to windows to reduce the view angle towards the noisy roads, thus lower the noise levels at the flats. Single-aspect building design with non-sensitive receivers, such as kitchen and bathroom, facing the noise sources could be a very effective measure to solve severe noise issues. Long Ching Estate in Yuen Long (Figure 3) is an example of successfully mitigating noise impact with single-aspect block design.
Under extremely severe conditions, indirect mitigation measures in the form of window insulation and air conditioning could be considered as the last resort. However, it would be at the expense of enjoyment of natural ventilation.

4. Innovative Mitigation Measures

Apart from the above traditional noise mitigation measures, we have recently developed more innovative measures at the receiver end for mitigating road traffic noise in order to maximize site development potential and improve the living environment. These are described in details as follows:

4.1 Adoption of Site-Specific Modular Flat

To suit site constraints, we sometimes use site-specific modular flat design in public housing projects to achieve self-screening effect against traffic noise. Subject to compliance of the Building Regulations, the environmental performance can be enhanced by repositioning the windows in a tailor-made flat layout. The site-specific modular flat design was first adopted in the Cheung Sha Wan Estate. This design has further been used in another public housing site of Tuen Mun Area 54 Site 2, in which fixed windows are positioned at protruded rooms facing major traffic noise source and openable side windows are provided with lower noise impact to meet the noise standards. These protruded rooms could also reduce the view angle of the adjacent recessed rooms for noise protection. A comparison of a typical layout of this site-specific modular flat with a standard modular flat is shown at Figure 4. Such specific design can ameliorate noise impact by 2 to 3 dB(A). When using this design, various operational factors including field of vision, ventilation, natural lighting, and window cleansing requirements have to be carefully considered.

4.2 Acoustic Window

At sites which are close to very noisy roads such as the San Po Kong public housing development abutting Prince Edward Road East due for completion in 2017, conventional mitigation measures would not be sufficient to abate the noise impact. In this case, the unmitigated noise level at the site boundary was anticipated at 85dB(A). Apart from other conventional measures, the project team needed to work out innovative measures to further attenuate 8dB(A) in order to meet the 70dB(A)
noise standard as a rezoning requirement. Hence, we collaborated with 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 5). Initially, we commenced our exploration by conducting laboratory tests on this window design concept in the laboratory of HKPolyU. The purpose of this laboratory exploration was to verify the noise attenuation performance of the window system and how the performance would be affected by other parameters including configuration of the window pane and opening, separation of the panes, angle of noise incidence and use of noise absorption material in the window system.

A total of 20 nos. window casement design and over 200 testing scenarios with noise source variations of line sources and point sources had been carried out in the laboratory testing. The laboratory testing provided very promising results.

Further to the laboratory exploration, detailed assessment had to be undertaken to evaluate the noise attenuation which could be applied to the proposed acoustic window sets to be installed in the housing project. After deliberation among the Research Team, it was considered that the effective noise attenuation of the acoustic window should be established by direct comparison of its performance against that of conventional window under in-situ noise environment. Subsequently, in 2010, full scale mock-up flats installed with prototype acoustic window was set up on site for in-situ acoustic measurements (Figure 6).

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. Upon testing for different flats and window scenarios, it was established that the acoustic window could achieve noise attenuation up to about 8dB(A).

With the employment of acoustic window system, 100% predicted noise compliance with the noise standard can be achieved. We will carry out more noise monitoring upon completion of the project. During the design process, ventilation and other operational factors like window cleansing, clothes hanging and long term maintenance have been carefully considered (e.g. detailed design for...
the accessibility of the various parts of the window and clothes drying rack).

5. A Case Study of Acoustic Balcony

5.1 Acoustic Balcony (Arc-screen to First Generation)

Wing Cheong Estate development, abutting West Kowloon Corridor, is exposed to severe road traffic noise impact. Although a Y-shaped block design was adopted to reduce the view angle to the West Kowloon Corridor and provide some self-screening effect, initial road traffic noise assessment indicated that the unmitigated case would achieve a noise compliance of only 46% and a maximum noise level of 78dB(A). Since the site and road configuration rendered conventional noise measures 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 effectiveness of the measure. With the promising desktop results, the project team subsequently proceeded with a 3-storey full scale model prototype installation for the in-situ noise measurements. Various arc-screen options, different materials and test scenarios have been worked out for testing. A total of about ten thousand acoustic measurements have been taken in the Dongguan model (Figure 7). Results demonstrated the effectiveness of noise attenuation by the arc-screen.

![Figure 7: Site Mock-up Model at Dongguan and Measurement Scenarios](image)

After 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 8.

![Figure 8: Initial Arc Screen Design Concept and First Generation of Acoustic Balcony Design](image)

Together with the application of noise absorptive linings, the Acoustic Balcony could achieve maximum noise reduction up to 6.4dB(A). Upon completion of the building works in July 2013, on-site noise verification has been conducted, confirming the predicted noise reduction could be achieved.

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 cleaning as well as long term maintenance. According to the resident survey taken after its occupation in 2013, this Acoustic Balcony design could effectively reduce noise by about 2 to 6 dB(A) and much to the satisfaction of the tenants.

5.2 Acoustic Balcony (Enhanced Design)

Although successful in developing the innovative measures of acoustic window and acoustic balcony (Arc-screen to First Generation), we are not complacent. We looked into an enhanced Acoustic Balcony design (Figure 9), which amalgamates the acoustic window concept in the first generation of Acoustic Balcony. 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. This arrangement allows the ventilation path to be of decent width. Other auxiliary feature like noise adsorptive material at the wall and ceiling of the balcony and inclined panel projecting 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 9: Layout of Enhanced Acoustic Balcony Design](image)

After discussion among our project team, EPD and HKPolyU’s experts, it was considered that the effective noise attenuation of the enhanced Acoustic Balcony should be established by direct 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 base 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 10). The existing vacant school building would be demolished and the site would be developed for a public rental housing development providing some 800 flats for 2019/2020. This housing development is the first pilot project adopting the enhanced Acoustic Balcony design. Both in-situ traffic noise source and loudspeaker noise source had been used for the measurements.
At least 20 microphones were employed to measure simultaneously the exterior and interior noise levels of the mock-up flats under 23 scenarios of different flat/enhanced balcony settings. Besides, loudspeaker arrays at different offset distance representing different inclination angle of noise source were employed to simulate the flats at various levels. 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 10dB(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. At the moment, we are still 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.

6. Collaboration with EPD and Other Stakeholders

Over the years, HKHA has been working in close collaboration with EPD 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. Experience demonstrated that such a collaboration approach with other stakeholders is essential and practicable to develop innovative measures for the benefit of the community. HKHA welcomes collaboration with other stakeholders in the construction industry to further explore innovations and to share and exchange the experience gained during the research and development processes.

7. Conclusion

Given the high density urban setting in Hong Kong, it is a great challenge to build a green, safe, healthy and sustainable living environment against various pollution sources, with noise being one of the major issues. We work with the industry to overcome these challenges. Over the years, through close collaborations among stakeholders in the academic institutes, regulatory authorities and construction industry, HKHA has successfully developed various innovative noise mitigation designs and measures for maximizing the development potential of public housing sites and for improving the environmental quality of housing estates, permitting more restricted sites to be used effectively and efficiently to meet Hong Kong’s housing needs as a whole.

We have holistic vision and effective operation, involving internal and external parties, caring for people, environment and maintaining cost-effectiveness. Innovative solutions come along with these challenges. Hong Kong will continue to grow and mature, in face of challenges and innovation. We serve, 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-rise, high density urban environment.

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