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NOISE CONTROL FOR A BETTER ENVIRONMENT

Development and application of specially designed windows and balconies for noise mitigation in Hong Kong

CHEUNG, Ka Man Carmen[1]
WONG, Hoi Ying Connie[2]
HUNG, Wan Choi Tim[3]
LAU, Kwok Keung[4]

Environmental Protection Department, the Government of the Hong Kong Special Administrative Region, the People's Republic of China

YIM, Yu Chau Stephen[5]
LEE, Yun Cheung Rudolf[6]

Hong Kong Housing Authority, the Government of the Hong Kong Special Administrative Region, the People's Republic of China

ABSTRACT

To cope with strong housing demand, the Government of Hong Kong Special Administrative Region has been exerting tremendous effort in searching more housing sites. Many sites under searching are inevitably located close to various noise sources like heavily trafficked roads and some are separated by just 10 to 20 metres. To facilitate housing supply without compromising the living quality of future residents, Environmental Protection Department (EPD) has made reference to limited overseas studies and experiences in ventilating windows to come up with the concept of specially designed window, which can help reduce noise entering into the flat while meeting the statutory natural ventilation requirements in Hong Kong. In recent years, the EPD has been collaborating with Hong Kong Housing Authority who is responsible for planning and building public housing, to put the concept into application and to further develop another form of noise mitigation designs - specially designed balconies. These specially designed windows and balconies were demonstrated capable of offering significant noise reduction. This paper gives an account of the development of these specially designed windows and balconies and shares the experience in promoting and facilitating the private residential developers and other stakeholders to apply these designs in Hong Kong.

Keywords: Road Traffic Noise, Noise Mitigation Design, Specially Designed Window and Balcony

[1] carmenkmcheung@epd.gov.hk
[2] conniewong@epd.gov.hk
[3] timhung@epd.gov.hk
[4] npg_kkl@epd.gov.hk
[5] stephen.yim@housingauthority.gov.hk
[6] rudolf.lee@housingauthority.gov.hk

1. INTRODUCTION

Hong Kong is a hyper-dense city with a population exceeding 7 million in 110,000-hectare land of which 85% is mountainous. Given this compact cityscape and a huge housing demand, many housing developments are inevitably planned in close proximity to various noise sources, in particular highly trafficked expressways and local roads. With a view to safeguarding an acceptable noise environment for future occupants, the Environmental Protection Department (EPD) seizes every opportunity to intervene in planning of housing developments and the Hong Kong Housing Authority (HKHA) endeavours to plan public housing developments against noise impacts.

As mentioned in **[1]**, the Hong Kong Planning Standards and Guidelines (HKPSG) provides guidelines for developers to consider adoption of noise mitigation measures in new housing developments. Noise mitigation measures such as self-protecting building design and arrangement, integrated building-noise source design and purpose-built noise barrier, etc., should be explored and implemented wherever practicable in order to meet the road traffic noise planning standard stipulated in the HKPSG for housing developments. However, as housing sites are getting closer and closer to the noise sources, these conventional measures are gradually found insufficient to bring down the noise to meeting the planning standard and acoustic insulation, which will practically deprive the residents of outdoor activities and an “open-window” life style, is needed to address the potential noise problems.

An optimum building design for human comfort and hygiene should not simply provide an acceptable noise environment and need to balance against other needs and constraints such as natural ventilation and lighting. While the provisions of noise mitigation measures at building envelope might well attenuate the noise level inside flat, they may adversely affect the ventilation performance required under Buildings Ordinance of Hong Kong. It becomes a challenge for developers (including HKHA) to address the paradoxically conflicting requirements. With a view to creating an acoustically and environmentally liveable environment, the EPD and HKHA have always strive to stimulate research and development of new noise mitigation designs.

Some new noise mitigation designs developed in Hong Kong have been briefly introduced in **[1], [2], [3]** and **[4]**. These are specially designed windows and balconies termed as acoustic window and enhanced acoustic balcony. They could be in different forms while serving the same purpose - screening incoming noise and maintaining adequate air ventilation for the housing units. The paper is going to discuss more in-depth the development of these specially designed windows and balconies by going through some case studies, and to share the experience of the HKSAR Government in promoting and facilitating housing developers and other stakeholders in real application of these innovations.

2. ACOUSTIC WINDOW

2.1 Top-hung Acoustic Window

The design of a top-hung acoustic window consists of a top-hung window at high level and a horizontal fin extending out from the bottom of the window. The window can be opened outwards for natural ventilation, while incoming noise can be effectively screened, minimizing the impact caused to the residents. Coupled with noise absorption material on the inner pane of the window and a pelmet in the indoor area behind the top-hung window the noise reduction performance can be enhanced. To maintain adequate natural light and good open view from indoor area, a fixed glazing, which needs not be opened for ventilation, are usually installed below the top-hung window. By comparing the indoor noise levels with acoustic window and with conventional window, the noise reduction offered by acoustic window cannot estimated.

Acoustic window of top-hung type has been considered by a developer in some private housing developments for mitigating road traffic noise. For instance, a residenital development located in Pak Shek Kok, which was completed in 2012, adopted top-hung acoustic windows in the form of recessed window to face the noise source **[*Figure 1*]** for reducing road traffic noise from Tolo Highway. Noise reduction of 4 dB(A) was achieved.

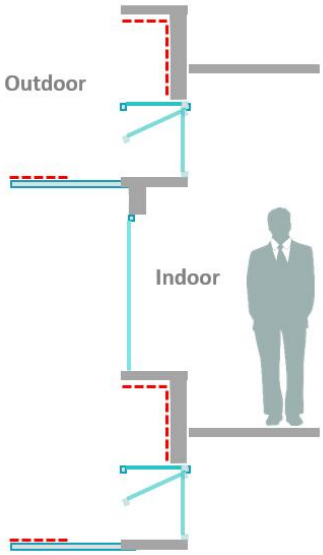

Figure 1 *– Top-hung acoustic window in a private housing development*

Another application of top-hung type acoustic window is in a residential development near Hong Tsuen Road in Sai Kung. The window is coupled with transparent sound absorbent (e.g. micro-perforated design) on the inner side and a pelmet is added indoor. A noise reduction of 5.5dB(A) was revealed in laboratory test.

2.2 Baffle-type Acoustic Window

Baffle-type acoustic window basically comprises two layers of window which can be aligned in a way that the pane of inner window is behind the opened outer window for reducing the noise entering into the room. There are two main kinds of baffle-type acoustic windows. One is with vertical sliding inner window which is basically only applicable in student hostels and another is with horizontal sliding inner window sliding inner window in residential developments.

For the first type, the outer layer consists of a solid parapet or fixed glazing at bottom and an opening at top, while the inner layer is of a window which can be slid up and down. To further enhance the noise reduction effectiveness, sound absorbent is applied at top and both sides of the inner frame.

A real life application is in Polytechnic University (PolyU) Student Hostel Phase 3 at Hung Hom **[*Figure 2*]**, which was completed in 2012. In tackling the road traffic noise from Chatham Road North and Fat Kwong Street, EPD engaged discussion and review with PolyU on the window design and in-situ testing during the planning phase of the hostel. Eventually this kind of acoustic window was adopted and the maximum noise reduction was found to be 8 dB(A).

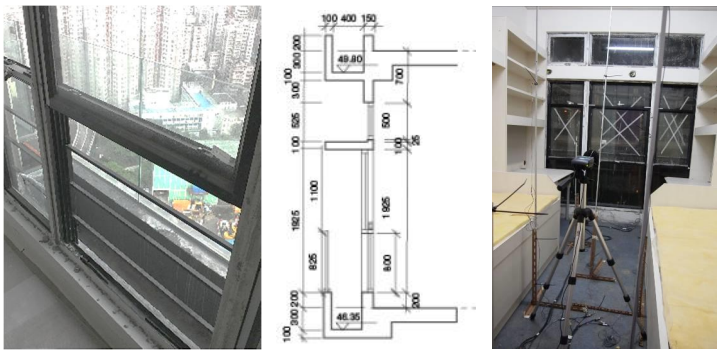

Figure 2 *– Baffle-type acoustic window in PolyU Student Hostel at Hung Hom*

2.2.1 King Tai Court, San Po Kong

The first residential development which adopted baffle-type acoustic window was a public housing development – King Tai Court in San Po Kong, which was designed and completed by HKHA in 2017. The window design is comprised of a horizontal sliding window at the inner layer, and a side-hung window, which can be pushed to open, on one side of the outer layer and a fixed glazing on the other side **[*Figure 3*]**. The glazing of the sliding inner window serves as a “baffle” for screening off the noise passing through the opened outer window when it is slid behind the opened outer window. The air gap in between the two layers allows natural ventilation. Only small portion of noise reaching the opened side hung windows can enter into the housing unit, either directly or through multiple reflections of the window elements.

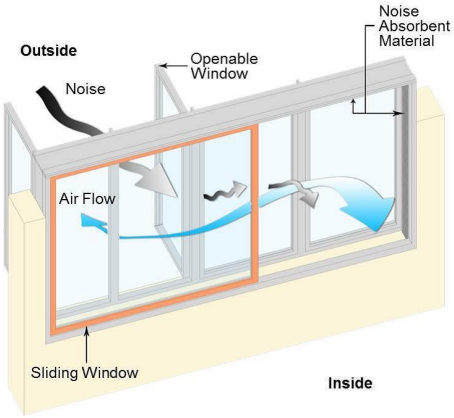

Figure 3 *– Working mechanism of baffle-type acoustic window*

The site was directly affected by heavily trafficked Prince Edward Road East and a road traffic noise level of 85 dB(A) was initially predicted in unmitigated scenario. Conventional noise mitigation measures including building setback, building block orientation and architectural fins were subsequently introduced to bring down the estimated noise level from 85 dB(A) to 78 dB(A). Yet an exceedance of 8 dB(A) against the requirement of HKPSG, i.e. 70 dB(A), was still anticipated.

This challenging situation stimulated the exploration of new noise mitigation measures, and hence formation of a research team comprising HKHA, EPD and PolyU. The three parties were in proactive and close collaboration on working out the acoustic window design **[4]**, which functioned as a modified double-glazed window with offset openings to allow natural ventilation. In mid-2009, laboratory experiments were conducted on testing the window design to verify feasibility and order of noise reduction. A series of on-site mock-up tests were subsequently carried out to obtain a more accurate estimate on the effectiveness of acoustic window by comparing its in-situ performance against that of a conventional window. The acoustic window was also equipped with sound absorptive material at the head and jamb of window frame to further enhance the sound reduction. A noise reduction up to 8 dB(A) was expected and thus the acoustic design was applied in this housing development to meet the planning standard of 70 dB(A).

Figure 4 *– Acoustic window in King Tai Court, San Po Kong*

2.2.2 Kwai Tsui Estate, Kwai Chung

In 2018, another public housing development – Kwai Tsui Estate designed with acoustic window was completed by HKHA in Kwai Chung. The site is at some 20 m away from a heavily trafficked urban trunk road, resulting in a predicted high road traffic noise level, which required consideration of both conventional and new noise mitigation measures.

In developing this challenging site, HKHA has close dialogue with EPD to work out feasible noise mitigation solutions. Maximum building setback was incorporated into the design layout. X-shaped block design was introduced to minimize the angles of view of most flats to adjacent roads. A canopy and several architectural fins were also proposed to reduce the road traffic noise impact. In spite of these conventional noise mitigation measures, an exceedance of 8 dB(A) was still expected. To mitigate severe traffic noise impact, acoustic windows with sound absorptive material on frame were proposed to the affected flats **[5]**.

On-site noise measurements were conducted upon the project completion to evaluate the noise reduction performance of the acoustic windows.

Figure 5 *– Acoustic window in Kwai Tsui Estate, Kwai Chung*

The noise reduction performance of the acoustic window was determined by comparing the road traffic noise levels measured indoor under “conventional” mode (i.e. glazing of inner window slid away from the opened outer window) and under “acoustic” mode (i.e. inner window glazing behind the opened outer window). Noise measurements at 5 indoor points determined with reference to ISO 16283-3 were conducted at the outmost flats facing directly to major roads on the middle and high levels. In addition, noise measurements were conducted at 1 outdoor point at 1 m away from façade for monitoring and correction for variation of road traffic noise levels under different modes **[*Figure 6*]**. All toilet, kitchen and main doors were fully closed during noise measurements. The results showed that noise reduction performance were comparable to the predicted values.

Figure 6 *– Setup of measurement points*

2.2.3 A Private Residential Development in North Point

EPD provided facilitation for development and application of new noise mitigation measures not only in public residential development but also private ones. During the planning stage of these private residential developments, the EPD has close dialogues and meetings with developers to explore feasible solution. Besides, EPD had organized workshops and seminars to engage private housing developers, relevant professionals and consultants in the industry to exchange ideas and experiences on new measures.

With continuous effort and collaboration amongst EPD and developers, newer designs of new measures had been incorporated into new residential developments to combat road traffic noise problem. A new acoustic window system was adopted in a private housing development situated in North Point, which is directly facing a heavily trafficked highway. The system is comprised of a fixed glazing in the middle and two openable windows at two sides at the out layer, and two transparent sliding panels at the inner layer **[*Figure 7*]**. Under "conventional" mode, the inner sliding panels would be behind the outer fixed glazing and noise can directly enter into room through the two opened outer windows without any screening. When the two sliding panels are slid behind the opened outer windows under the acoustic mode, the panels can serve as "baffles" to screen off substantial amount of noise from entering into the room.

To further reduce noise entering into the flat, the two transparent sliding panels were applied with Micro-Perforated Absorber (MPA), which was a transparent membrane punched with small holes to dissipate sound energy. Perforated panel with sound absorptive material filled inside was also installed in the window frame to absorb incoming sound.

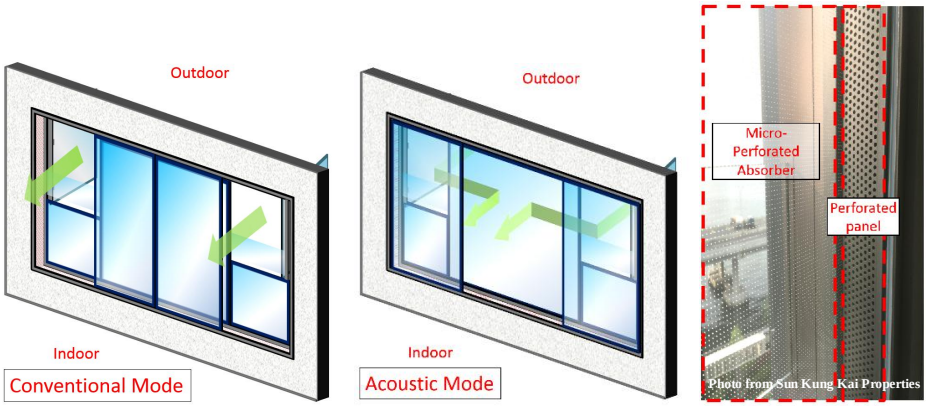

***Figure 7**: Acoustic window in a private residential development in North Point*

Noise measurements in the as-built flats found that the baffle-type acoustic windows were effective to reduce the noise entering into the flat as planned.

3. ENHANCED ACOUSTIC BALCONY

3.1 Wing Cheong Estate, Sham Shui Po – First Generation of Acoustic Balcony

Enhanced acoustic balcony was firstly designed and adopted in a public residential development – Wing Cheong Estate in Sham Shui Po completed by HKHA in 2013. The development was located at some 35 m away from a heavily trafficked road named West Kowloon Corridor. Due to site constraints, building setback and on-site noise barrier were impractical. A Y-shaped block design and provision of architectural fins were thus incorporated to minimize the angle of view to the West Kowloon Corridor. Yet the road traffic noise level up to 78 dB(A) was still predicted in unmitigated scenario, i.e. a 8 dB(A) exceedance over the planning standard.

To address the problem, the concepts of arc-screen design and enhanced acoustic balcony as shown in ***Figure 8*** were therefore explored. HKHA conducted desktop numerous testing on the practicability of the design. Ray tracing computer simulations were also conducted for assessing the noise reduction effectiveness before real application. After the simulation results were reviewed and analysed with EPD, noise measurement in a prototype flat was considered helpful in verifying the effectiveness of the enhanced acoustic balcony. HKHA, partnered with EPD, thus kicked off a series of site tests.

In 2008, the noise reduction effectiveness of arc-screen design and several enhanced acoustic balcony designs were tested in a 3-storey full-scale-mock-up building in Dongguan, China. The road traffic noise was simulated by a long array of loudspeakers. In order to test the noise reduction effectiveness on different floors, the loudspeaker array was set at different separating distances from the mock-up building, representing different elevation angles. Noise levels were measured by microphones at 1 m from the exterior of the façade to determine the noise reduction. It was eventually decided to adopt enhanced acoustic balcony instead of arc screen

design in the development. With repeated testing, the first generation of enhanced acoustic balcony was eventually worked out, featuring a solid balcony parapet, an inclined glass panel, extended side walls, noise absorptive linings on the side walls and balcony ceiling **[*Figure 8*]**.

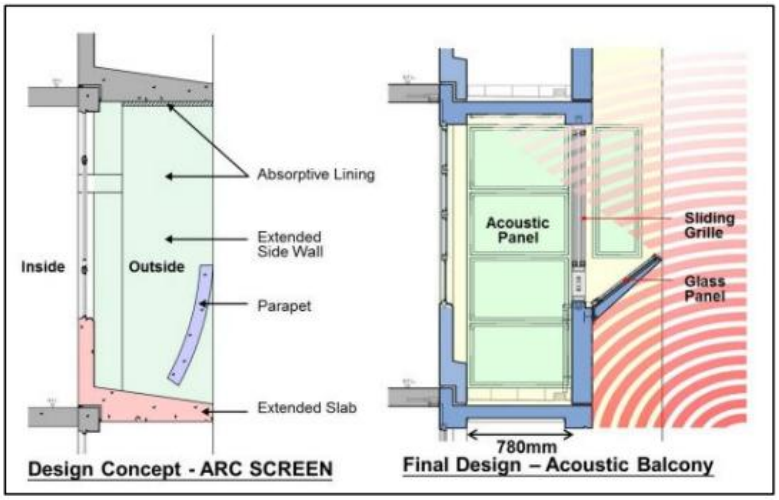

Figure 8 *– Working mechanism of enhanced acoustic balcony*

After completion of Wing Cheong Estate, both HKHA and EPD carried out in-situ noise measurements to evaluate the actual noise reduction of the enhanced acoustic balcony. Some flats facing the West Kowloon Corridor were chosen for carrying out noise measurement at 1 m from the facade. The results indicated that the enhanced acoustic balcony was able to reduce the incoming road traffic noise by 2 to 6 dB(A) on different floors. Besides, according to the resident survey taken after its occupation in 2013, this acoustic balcony design were much to the satisfaction of the tenants **[*Figure 9*]**.

Figure 9 *– Acoustic balcony in Wing Cheong Estate, Sham Shui Po*

3.2 Public Housing Development in Wing Tai Road, Chai Wan

Given the success of the aforementioned enhanced acoustic balcony, HKHA and EPD made concerted effort in further enhancing its performance. By integrating the concept of acoustic window into the first generation of enhanced acoustic balcony, the second generation of enhanced acoustic balcony was developed as shown in ***Figure 10***. The additional feature is a sliding screen installed above the parapet in front of the balcony door to ameliorate the incidence of noise through the balcony door into a flat. Similar with previous experience, HKHA engaged the Hong Kong Polytechnic University (HKPolyU)'s acoustic professionals to conduct an in-situ noise measurement for better estimation on the noise reduction effectiveness.

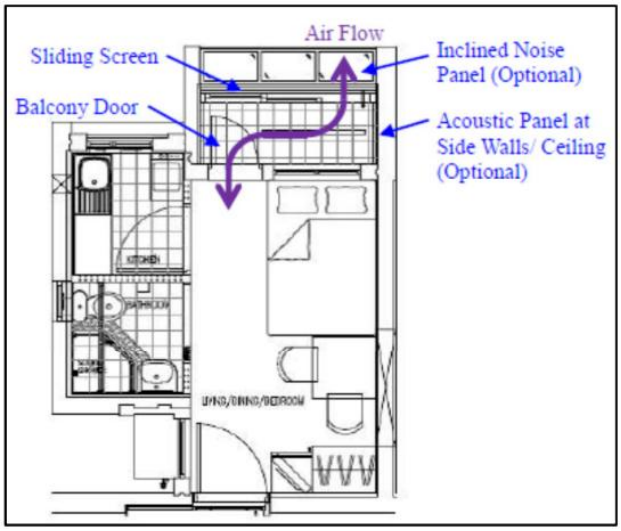

Figure 10 *– Design of enhanced acoustic balcony*

In July 2015, full-scale mock-up tests were commenced at a vacant school situated at Yau Yue Estate. Conventional side-hung window and enhanced acoustic balcony were installed in two side-by-side mock-up flats on 4/F **[*Figure 11*]**. Same as the methodology in evaluating noise reduction of acoustic window, the noise reduction offered by an enhanced acoustic balcony was worked out by comparing the average noise levels inside the flat with conventional window and that with acoustic balcony. The tests were conducted during peak hours with the heaviest traffic flow on a nearby District Distributor - Wing Tai Road. As the elevation angle of the mock-up flats from Wing Tai Road was not large, an array of loudspeakers was used to simulate the noise source with various elevation angles, including 15°, 30°, 45° and 60°, with the flats. 23 scenarios with different noise mitigation features were tested, e.g. with and without sound absorption materials at side walls and ceiling of balcony, with and without inclined panels projecting out from parapet.

Figure 11 *– Mock-up test in Wing Tai Road, Chai Wan*

The results indicated that noise reduction can be achieved up to 12 dB(A), depending on elevation angle from the road and other auxiliary feature like noise absorptive material at the wall and ceiling of the balcony and inclined projecting panel from the parapet. Therefore, it was demonstrated to be an effective design for noise mitigation whilst at the same time allowing natural air ventilation for the habitable area of the flat. The findings were encouraging to the whole project team including HKHA, EPD and PolyU's experts. HKHA has incorporated such enhanced balcony designs into public housing developments where necessary. The first is the public residential development later developed in this test site, which is exposed to a maximum road traffic noise level of 79 dB(A).

4. CONCLUSIONS

EPD and HKHA endeavoured in developing new noise mitigation measures with a view to provide acceptable noise environment. The acoustic windows and balconies are useful measures to deal with challenges of noise impact in housing developments which are located at difficult locations. This paper shares application of the new acoustic windows and balconies that are being increasingly used in housing developments in Hong Kong.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. CHAN I., TONG V., HUNG T. and LAU K.K.*"The Development of Practicable Measures for Planning of Housing Developments against Road Traffic Noise Impacts in Hong Kong*", Proc INTER-NOISE 2017; 27-30 August 2017; Hong Kong, China 2017. p. 3997.

2. Ada YS FUNG, John HL HO, Stephen YIM, PK CHIU.“*Noise Reduction by Improving Building Envelopes - The Hong Kong Housing Authority Experience”*, Proc INTER-NOISE 2017; 27-30 August 2017; Hong Kong, China 2017. pp. 3078.

3. POON B., CHEUNG C., HUNG T. and LAU K.K. *“Development of Noise Mitigation Designs of Windows and Balconies for Housing Developments in Hong Kong*”, Proc 25th International Congress on Sound and Vibration 2018; 27-30 July 2018; Hiroshima, Japan. p. 3825.

4. HO J. and YIM S., HKHA, “*Application of Acoustic Window and Acoustic Balcony for Public Housing Development in Hong Kong*”, 2017 Environmental Paper Award HKIE Environmental Division, retrieved from http://ev.hkie.org.hk/en_it_events_inside_Past.aspx?EventID=852&&TypeName=Events+%2F+Activities