# Investigation and development of an empirical model for transmission loss of acoustic windows in alleviating road traffic noise impact

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## ABSTRACT

An Acoustic Window 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. 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. This baffle-type acoustic window is proved to reduce up to 8 dB(A) road traffic noise and is gaining popularity in residential developments of Hong Kong, particularly for those located in difficult sites in close proximity to heavily trafficked roads. This paper presents the experimental results from a study looking into the acoustical transmission loss of Acoustic Windows with respect to changes in window configuration and setting of line sources. Based on the experimental results, empirical models for noise reduction of Acoustic Windows are developed and investigated to assist quick design of Acoustic Windows for planning residential developments.

**KEYWORDS** Environmental noise; road traffic noise; noise mitigation design; acoustic window; empirical model
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### 1. Introduction

Hong Kong is commonly known as an international metropolis with compact skyscrapers. In 2019, the population was 7.4 million and the total land area is only 1,106 km$^2$. Since more than 80% of the land is hilly, developable land for residential buildings is limited. Many residential developments are inevitably planned in close proximity to various noise sources, e.g. highly trafficked expressways, local roads, fixed plants, railway, etc. Road traffic noise pollution is a particularly pressing environmental issue in Hong Kong. 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 barriers, etc., should be explored and implemented wherever practicable, in order to meet road traffic noise planning standard stipulated in the HKPSG for housing developments - 70 dB(A) L10 (1 hour) (Planning Department, 2014). Other conventional noise mitigation measures, including low noise road surfacing, noise-tolerant buildings (e.g. multi-storey car parks, shopping malls, retail buildings), podium/deck and architectural fins, are also commonly adopted in the planning of residential developments. However, residential developments are unavoidably getting closer and closer to multiple noise sources, so these conventional measures are gradually being found to be inadequate to screen noise for meeting the planning standard. While acoustic insulation is a last resort in attempting to abate noise disturbance, it will practically deprive residents of outdoor activities. In Hong Kong, with its warm and humid climate, it is neither economical nor environmentally friendly for residents to resort to air-conditioning under the provision of acoustic insulation. An “open-window” design is therefore considered important for mitigating noise and maintaining ventilation in the context of Hong Kong. An “open-window” design also goes in line with the international trend of pursuing sustainable living, where environmental noise can be controlled and the need for air-conditioning is avoided.

The acoustic window is a good solution to reduce noise inside flats. A baffle-type acoustic window is comprised of two layers of window, which can be aligned in a way that the pane of the inner window (i.e. sliding window) is slid behind the openable outer window (Figure 1). It is generally adopted by the Housing Department of the HKSAR Government in designing the new public housing layout and the window panes are generally 6 mm thick. The design is a win-win solution that promotes sustainable living – access to the outdoor environment with natural ventilation – and avoids the need to turn on air conditioning as in the case of acoustic insulation. In such an acoustic setting, noise entering into the room is partially reflected back outside and is partially disseminated when passing through the gap. With repeated laboratory testing, computer simulation, numerical analysis and on-site measurement, acoustic windows are demonstrated to be effective in screening noise entering residential flats, while maintaining natural air ventilation. There are two main kinds of baffle-type acoustic windows. One is with horizontal sliding, which is mostly applied in residential flats, and another one is with a vertical sliding inner window, which is basically only applicable in student hostels. Having said that, this study only focuses on horizontal baffle-type acoustic windows.

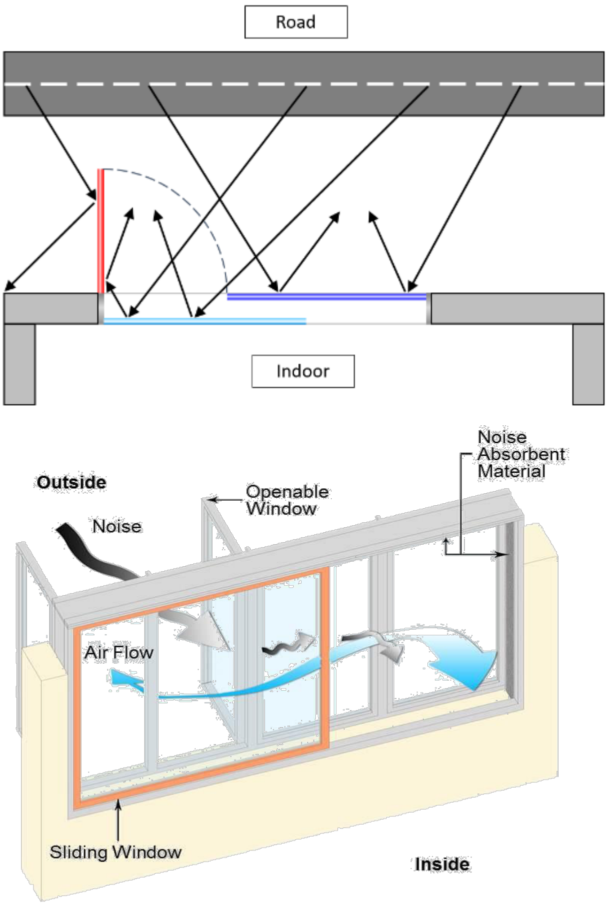


Figure 1. Noise screening mechanism of the baffle-type acoustic window.

The effectiveness of the acoustic window is indicated by its relative noise reduction (RNR), which is generally evaluated by the formula below. The RNR offered by an acoustic window is obtained by comparing it with the noise reduction performance of a conventional window. The noise reduction performance of an acoustic window is considered as the enhanced indoor noise reduction with an acoustic window installed compared to that with a conventional window (primary opening area is 1/16 of the floor area of the room) installed in the room.

$$RNR = (SPL_{indoor\ ,\ CW} - SPL_{indoor\ ,\ AW}) + \Delta SPL_{outdoor}\ , \quad (1)$$

where,
RNR = relative noise reduction, dB(A),
$SPL_{indoor\ ,\ CW}$ = indoor sound pressure level with a conventional window, $L_{10}$, dB(A),
$SPL_{indoor\ ,\ AW}$ = indoor sound pressure level with an acoustic window $L_{10}$, dB(A).
$\Delta SPL_{outdoor}$ = change in outdoor sound pressure levels, $L_{10}$, dB(A).

The usual method of evaluating the noise reduction effectiveness of an acoustic window is by conducting a measurement test. Before a designed acoustic window is actually put into place in a residential development, laboratory tests are usually conducted on the sample acoustic window. A simulated traffic noise source is placed in one side of the test chamber as the source room, and microphones measuring the noise level are placed in the other side of the chamber as the receiving room. The acoustic transmission loss can be measured by the noise level difference across these chambers. However, this kind of measurement requires resources and time, and the cost could be high when window designs are changing from time to time in the course of residential development planning. Seeing this problem, this study attempted to develop an empirical model to predict the acoustic transmission loss of an acoustic window with alteration of different parameters, with a view to gauge the instant noise reduction performance of an acoustic window when only its major parameters are known.

## 2. Literature review of previous work related to prediction models of acoustic windows

Similar to Hong Kong, many countries have road traffic noise standards for new roads, including China, Japan, Australia, Canada, the USA, UK, France, Sweden and Germany. Yet most of them do not apply acoustic windows as extensively as in Hong Kong in order to mitigate traffic noise.

The prototype of this acoustic window was a partially opened double-glazed window. Almost 50 years ago, it was proven by laboratory and field tests that partially opened double glazing performs about 10 dB(A) better than partially opened single glazing, and tests were carried out to evaluate the noise reduction from different double glazing openings (Ford and Kerry, 1972; Ford and Kerry, 1972b). It works like a plenum to mitigate incoming duct noise which results in transmission loss and allows air to penetrate from the opening, across the plenum to the indoor environment. Numerous research projects have been underway worldwide to study the different configurations of such acoustic window and respective noise reduction effectiveness. In general, the design of acoustic windows requires considerations not only of their applicability to common building facades and compliance with statutory requirements regarding ventilation and lighting (Building Department, 2015), but also the optimum configuration for achieving targeted noise reduction. Research has found that transmission loss of a plenum window can be improved by decrement of the opening sizes and gap spacing (Du et al., 2019). In the recent 10 years, more studies have demonstrated that such plenum windows with staggered positions are capable of reducing indoor noise levels and can reach 6 dB(A) transmission loss at some low frequencies. Furthermore, plenum windows with the right dimensions of window void could offer better acoustical protection to the indoor environment (Tong et al., 2015).

The following formula was put forward to calculate the insertion loss (IL) of a plenum window with respect to the order of one-third octave band (i), band level of normalised traffic noise (N) and reverberation times (R).

$$\mathrm{IL} = -10\log_{10}\left(\frac{\sum_{i=1}^{18} 10^{0.1(N_i - R_i)}}{\sum_{i=1}^{18} 10^{0.1N_i}}\right). \quad (2)$$

There is also another formula suggested (Li et al., 2019) to obtain transmission loss by including the size of the outer window opening (woh), diffracted field directivity (Q), gap width (g), distance between the centres of the two window openings (d), reverberation field attenuation (K) and plenum cavity constant (R). However, these parameters might not be readily available when a design for an acoustic window is proposed by a project architect or environmental consultant. Site-specific factors are not taken into consideration in the formula either. Another empirical model is needed which can enable quick checking and is easily understandable to facilitate use for practitioners.

$$\mathrm{TL} = -10log_{10}\left[w_o h\left(Q\frac{g}{4\pi d^3}\right) + \frac{K}{R}\right]. \quad (3)$$

There are many factors that contribute to the effectiveness of acoustic windows, including outdoor noise level, indoor noise level, elevation angle from the road segment, outer window opening area, overlapping length, window height, gap width, etc. However, the correlation between transmission loss of an acoustic window and the aforementioned variables is not direct or simple. In this research paper, a simplified equation is developed with the aim of predicting the indoor noise level with an acoustic window with respect to various factors, and hence derive the acoustic transmission loss of a particular dimensioned acoustic window. A total of 33 sets of measurements with 1:1 acoustic windows were used to develop the simple empirical prediction model. Data from laboratory experiments and numerical analysis from different resident developments are used to validate the proposed equation. Although some scale models may indicate that the orientation of the noise source has some effect on the acoustic transmission loss of an acoustic window other than the outer window opening size and gap width, etc. (Tong and Tang, 2013), the influence of source orientation is not taken into consideration in this study for the sake of simplicity. This limitation of the study is an opportunity for future study.

Evaluation of the noise reduction effectiveness of different window settings with linear regression models from real measurement data was proposed in the research by Locher et al. (2018). It was focused on road traffic as the noise source. However, their research work differed from this study in terms of evaluation methods. They only evaluated the in-out differences of windows in various settings, e.g. open, tilted and closed, while this study examines the RNR of acoustic windows, which is a localised indicator acoustic window in Hong Kong and can represent the additional benefit brought by it compared to a conventional window. For the sake of simplicity, this study does not rely on a finite element model as the validating tool compared to other research (Sieck, 2013).

## 3. Methodology adopted to develop the proposed empirical model

A total of 33 sets of measurement data with 33 different RNRs were adopted to develop the empirical model. Table A1 provides the detailed measurement parameters and measured noise levels with background noise deducted.

### *3.1. Twenty-one sets from the mock-up test*

Twenty-one sets of measurement data came from a mock-up test. The traffic noise source was simulated by loudspeakers and an 8 $m^2$ mock-up flat was installed with an acoustic window. It was an open air outdoor test site in Huizhou, China with an area of over 650 $m^2$. The test ground was hard paved with concrete without any substantial building, structure or obstacle nearby which might interfere with the measurement result. Conventional windows with opening sizes just meeting the ventilation requirement were set up and tested separately. The 21 sets of RNR came from measurement with variation in source orientation (-150° to 150°), elevation (30° and 60°), outer and inner window opening size, overlapping length (100 mm, 300 mm and 500 mm), gap width (100 mm and 175 mm).

The road traffic noise source was simulated by a 21 m linear array of 11 3-way loudspeakers covering the frequency range of 39 Hz to 20 kHz, with a 2 m centre-to-centre separation distance. The frequency of road traffic noise ranged from 700 Hz to 1,300 Hz, while mostly concentrated at 1,000 Hz. L10 in the 1/3 octave band from 100 Hz to 5,000 Hz was used as the measurement parameter and the adopted loudspeaker system was able to generate random white noise with a continuous frequency spectrum. The simulated road traffic noise source was considered to sufficiently imitate an indefinite and continuous line source. Following the requirement in BS EN ISO 16283-3 (British Standards Institution, 2016) and ASTM E966-18 (American Society for Testing and Materials International, 2018), every loudspeaker was set to face towards the centre point of the outer window opening, in order to obtain even sound coverage over the window opening. The normalised traffic noise spectrum ranging from 100 Hz to 5,000 Hz under BS EN 1793-3 (British Standards Institution, 2012) was adopted to convert the white-noise acoustic transmission loss into a single A-weighting traffic noise reduction rating, which became the road traffic noise transmission loss presented in this study.

Considering the prevalent room size of newly completed residential developments, an 8 $m^2$ mock-up flat with a 3.4 m floor height was adopted as the testing facility. The flat was at least 2.8 m from the testing ground (Figure 2). Inside the mock-up flat, the walls and ceiling were made of gypsum board, and the floor was made of varnished plywood board. All the materials had a reflective surface with an average absorption coefficient of less than 0.05, imitating a completed flat without any furnishing and furniture. The sole door inside the mock-up flat was kept closed throughout the measurement period.

Twenty-one RNRs were obtained from the measurement, while all tested acoustic windows could fulfil the relevant statutory ventilation requirements. The outdoor noise level, which was indicated by the outdoor measurement point located at 1 m from the external façade of the mock-up flat, was maintained at 85 dB(A) throughout the measurement period in order to minimise the interference from potential background noise. With the above setup, average indoor noise levels were obtained in each test from at least five indoor measurement points (British Standards Institution, 2016). The 21 RNRs were used to develop the empirical model.

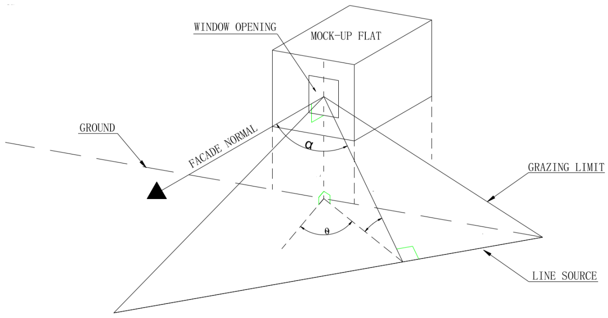


Figure 2. Mock-up test setup for obtaining the adopted data.

### *3.2. 12 sets from lab test*

Another 12 sets of measurement data obtained in a lab test were also used to develop the empirical model. Figure 3 shows the laboratory setup and Table A1 shows the detailed measurement parameters. There were two test chambers with an acoustic window fixed in between. The receiving room had an internal floor area of 21 $m^2$ floor and a height of 4 m. A linear array of 25 loudspeakers were adopted,

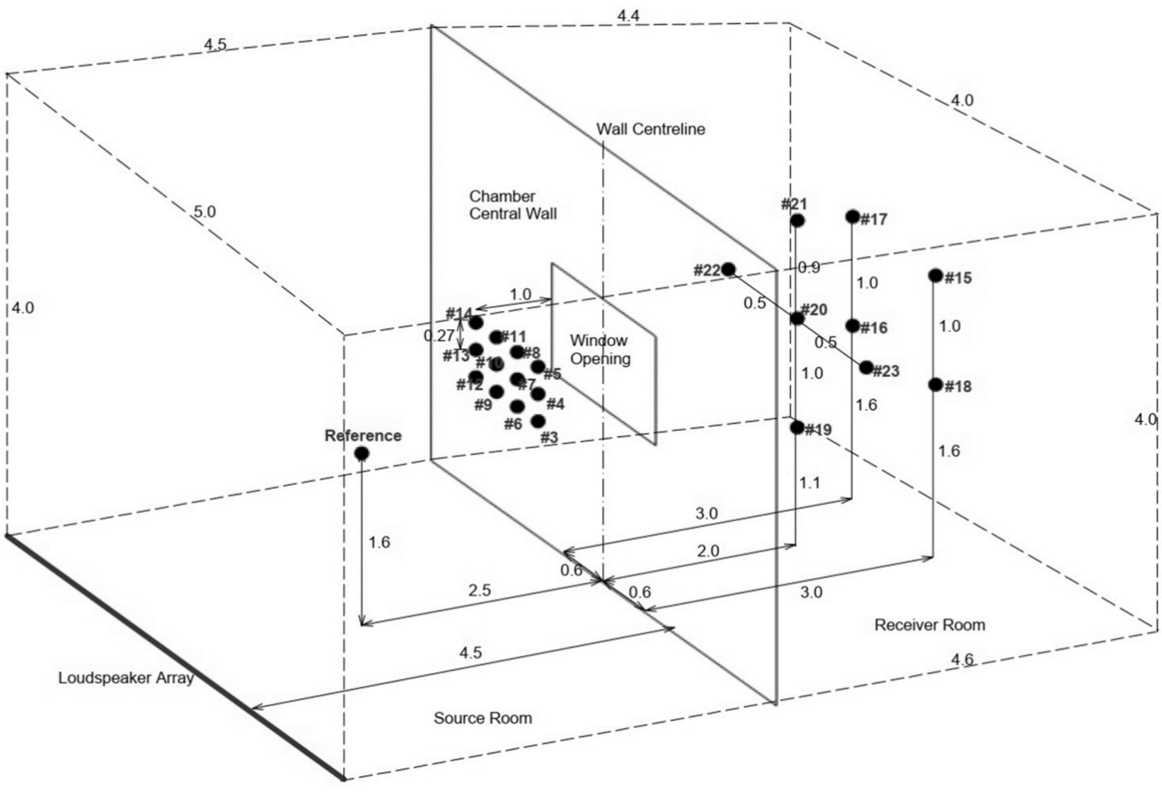


Figure 3. Lab test setup for obtaining the adopted data.

with all of them pointing towards the middle of the tested window. The average 'outdoor' noise level was measured by 12 microphones which were equally spaced at 1 m from the tested window, and the average indoor noise level was captured by nine microphones placed in the receiving chamber. Likewise, the normalised traffic noise spectrum in EN1793-3 (British Standards Institution, 2012) was applied for predicting the transmission loss across windows.

## 4. Developing the empirical model with measurement results

It is understood that varying the parameters of an acoustic window will affect its noise reduction performance. The general understanding of how various parameters affect the transmission loss of an acoustic window is highlighted in Table 1. Although the aforementioned factors are not comprehensive in determining transmission loss, they are major determinants that are reasonably supported by similar research (Li et al., 2019).

Table 1. Relationship between window parameters and noise reduction performance.

| Configuration | Change | Noise Reduction |
|---|---|---|
| Outer Opening Area | ↓ | ↑ |
| Inner Opening Area | ↓ | ↑ |
| Gap Width | ↓ | ↑ |
| Overlapping Length | ↑ | ↑ |
| Sound Absorbent | √ | ↑ |
| Additional Gaps | √ | ↓ |

To echo the intention of this research, an attempt at finding the influence of different parameters on the transmission loss across an acoustic window was made. The sampled transmission loss was found to have moderate statistical significance ($p$-value < 0.1) with a gap volume formed by the overlapping length, gap width and outer window opening height, the cross area formed by gap width and outer window opening height as well as the log function of outer window openings. However, these parameters were not able to provide sufficient explanatory factors for the transmission loss of the tested acoustic windows (Adjusted r-square = 0.2). Hence the model was modified and taken a step backwards to investigate the indoor noise level with which transmission loss can easily be found when the outdoor noise level is known.

Regression analysis was conducted to identify the influencing factors for the resultant indoor noise level after simulated road traffic noise was transmitted through the specified acoustic window systems. Apart from the outdoor noise level which will inevitably be a significant factor in explaining the measured indoor noise level, the square-root function of the void created by the gap width, overlapping length and window height (i.e. the volume created between the two window panes) will also have statistical significance in relation to the indoor noise level ($p$ value < 0.05). In coherence with the findings in Li et al. (2019) which suggested that the transmission loss of a plenum window (acoustic windows) depends significantly on the log function of outdoor opening area, the regression analysis also indicated the same finding ($p$ value < 0.05). The first regression model (model A) generally fits well with the measured data with an R-square value of 0.91. The below table presents the findings of the regression analysis and the resultant empirical Equation (4).

Table 2. Summary of regression analysis (Model A).

| Model A | | | | |
|---|---|---|---|---|
| | Co-efficient | Std. Error | t-Statistics | $p$-value |
| Constant | 6.2 | 6.9 | 0.9 | 0.4 |
| Outdoor noise level, dB(A) | 0.7 | 0.1 | 8.8 | <0.05 |
| Void volume^0.5, $m^3$ | 7.0 | 2.0 | 3.5 | <0.05 |
| log10(outdoor opening ($m^2$)) | 5.5 | 1.4 | 3.8 | <0.05 |
| Adjusted $R^2$ | 0.91 | | | |

$$y = 6.2 + 0.7SPL + 7.0(OL \times GW \times H)0.5 + 5.5log10(A), \quad (4)$$

where,

$y$ : Indoor noise level, dB(A)
$SPL$ : Outdoor traffic noise level $L_{10[1\text{-hour}]}$, dB(A)
$OL$ : Overlapping length of the acoustic window (m)
$GW$ : Gap width of the acoustic window (m)
$H$ : Outer window opening height (m)
$A$ : Area of outer window opening ($m^2$)

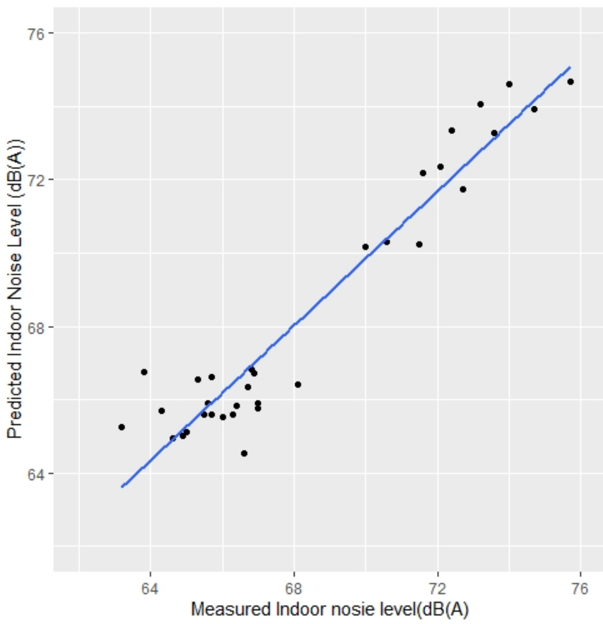


Figure 4. Model A: Comparison between predicted indoor noise level and measured noise level.

The model is in the form of a polynomial since the transmission loss of an acoustic window is a non-linear relationship between dependent and independent variables. The noise reduction of an acoustic window caused by the change in window parameters listed in Table 1 were verified by the model. Prior to the discussion of the correlation between different parameters and the indoor noise level with the presence of an acoustic window, it is spotted that the indoor noise level is a fraction of the outdoor noise level, i.e. 0.7 as indicated in the coefficient of Model A. One may immediately perceive that the transmission loss of an acoustic window will change with different outdoor noise levels. This finding appears little different from the standard acoustic concepts where the transmission loss should be independent of the outdoor acoustic environment. However, due to the limited sample size, the developed empirical model may not be mature enough to address whether possible confounding factor(s) in determining the performance of acoustic window exist. The findings in model A partially echo with the current understanding in Table 1 that a wider gap width between the window panes would allow more sound energy to enter from the external environment, thus resulting in a less efficient noise reduction system. On the contrary, the finding also suggested that the overlapping length might have an insignificant influence on the overall transmission loss of acoustic windows although a longer overlapping length is expected to enhance the noise reduction transmission loss. In order to verify such hypothesis, regression Model A was further enhanced by removing the overlapping length from the explanatory factors thus leading to Model B. The results indicated that Model B fits slightly better with the measured noise levels than Model A as the R-square value was improved to 0.92. The below table presents the findings of Model B and the revised empirical Equation (5).

Table 3. Summary of regression analysis (Model B).

| **Model B** | | | | |
|---|---|---|---|---|
| | Co-efficient | Std. Error | t-Statistics | *p*-value |
| Constant | 20 | 7.8 | 2.6 | <0.05 |
| Outdoor noise level, dB(A) | 0.5 | 0.1 | 5.6 | <0.05 |
| Cross-sectional area formed by gap width and window opening height ($m^2$) | 19.7 | 4.3 | 4.6 | <0.05 |
| Log(outdoor opening ($m^2$)) | 5.3 | 1.3 | 4.0 | <0.05 |
| Adjusted $R^2$ | 0.92 | | | |

$$y = 20.0 + 0.5SPL + 19.7(GW \times H) + 5.3log(A), \quad (5)$$

where,

$y$ : Indoor noise level, dB(A),
$SPL$ : Outdoor traffic noise level $L_{10[1\text{-hour}]}$, dB(A),
$GW$ : Gap width of the acoustic window (m),
$H$ : Outer window opening height (m),
$A$ : Area of outer window opening ($m^2$).

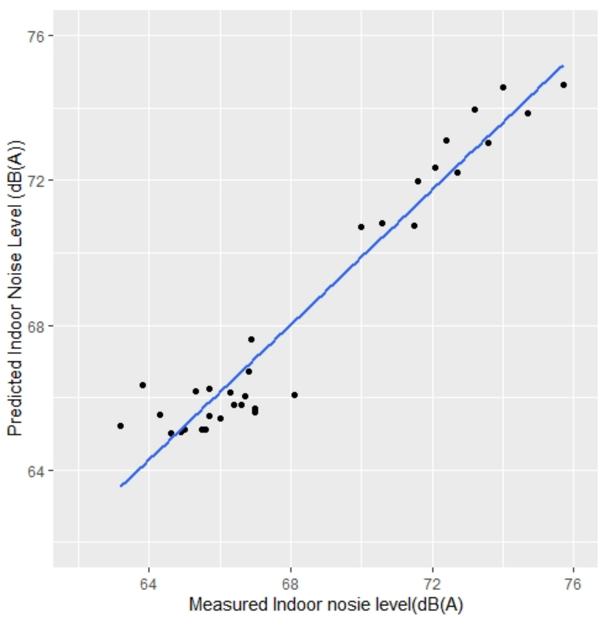


Figure 5. Model B comparison between predicted indoor noise level and measured noise level.

The regression analysis was not able to identify statistical significance with other parameters assumed to have an impact on the indoor noise level, including the elevation angle, and the indoor opening size.

Apart from the regression analysis of indoor noise level, a further analysis of the relative noise reduction (RNR) in dB(A) was also conducted. The sampled RNR was found to have statistical significance ($p$-value $< 0.05$) with the elevation angle, the log function of outer window opening as well as the log function of area ratio between acoustic window and conventional window outer openings (Adjusted r-square = 0.7). However, some factors established in Models A and B (e.g. relationships with overlapping length or gap width, etc.) were not identified.

## 5. Result and discussion

Since the empirical models were established through 33 sets of measurement data, it is worth knowing how well the empirical model fits into the real-life measurements at existing flats which have been installed with baffle-type acoustic windows. A total of 47 sets of noise measurements were used to evaluate the model. The data were measured in three newly completed residential developments installed with acoustic windows. The background information of the residential buildings is as follows.

Table 4. Summary of newly completed residential developments to be compared with the empirical models.

| Residential Development (Public / Private) | i | ii | iii |
|---|---|---|---|
| Room size ($m^2$) | 6.4-16.7 | 9.8 | 6.3–8.5 |
| Acoustic window outdoor opening area ($m^2$) | 0.9-1.4 | 1.2 | 0.9–1.2 |
| Acoustic window height (m) | 1.4 | 1.4 | 1.5-2.0 |
| Overlapping length (mm) | 340-634 | 340 | 355-400 |
| Gap width (mm) | 175 | 175 | 100 |
| No. of measurements | 18 | 24 | 5 |

The window parameters were fitted into the established empirical models (Models A and B), and the findings and comparison with measured noise levels are as follows for discussion.

Table 5. Summary of measured indoor noise levels at residential developments against the predicted values using Models A and B.

| Development | Measured | Model A | Model B |
|---|---|---|---|
| i | 58.5 | 59.1 | 61.0 |
| ii | 56.5 | 57.3 | 59.8 |
| iii | 67.5 | 64.5 | 64.1 |

*Mean of measured/predicted values, dB(A).

Both Models A and B were able to provide a prediction which was of a similar order to the measured values. However, the mean predicted values deviated from the measured values by 0.6 – 3.3 dB(A).

There are a number of reasons that could contribute to such phenomenon. The outdoor noise levels of the samples considered in the regression analysis were all taken at approximately 85 dB(A), while the measurements taken at these sites were all <85 dB(A). As such, the empirical model formulated above may not be able to verify the effect of lower noise level on the impact of the resultant indoor noise level. The transmission loss of acoustic windows might be easily interpreted to vary with different outdoor noise levels; however, another factor in determining the performance of acoustic windows – transmission loss of conventional windows – might also vary to the same degree. Secondly, empirical formulas were established based on an 8 $m^2$ and 21 $m^2$ room size, and variation in room size was rather limited. The indoor noise levels might also change according to room size due to reverberation of sound energy and the effect of reverberation was not taken into account in the regression analysis. Last but not least, since residential development iii is a private one, its window design is rather different from that of i and ii, i.e. the public developments. As a result, the predicted values generated by the models may deviate more from the measured value.

## 6. Future Development

The current regression model has a number of limitations in terms of room size and the sensitivity to different outdoor noise levels; however, it is meaningful to develop an empirical formula for the ease of making a quick estimation of the transmission loss of acoustic windows. When a certain configuration of acoustic window is proposed, the empirical model allows quick estimation of the indoor noise level and transmission loss; hence it could facilitate the design of noise mitigation proposals for development projects. It is clear that this very preliminary empirical model will need to be further enhanced in terms of the sample size included, incidence of outdoor noise levels, and even spectral characteristics of the acoustic transmission loss, etc. Furthermore, future measurement tests could also be tailor-made to confirm the earlier findings, including the insensitivity towards overlapping length and indoor window opening area, etc.

Moreover, there are many other parameters that have not been included in the experiment measurements but are worth investigating, such as source orientation, elevation, and use of absorptive materials, architectural fin and effect of reverberation time and room modes, etc. A correction factor may need to be employed to supplement the developed empirical formula.

## 7. Conclusions

It is well understood that the prediction of indoor noise level using theoretical equations or modelling for real-world situations is complicated. In order to have a quick grasp of the noise performance of acoustic windows, a simple regression model has been developed based on the measurement findings in 33 sets of baffle-type acoustic windows with variable window configurations. The regression models indicated that the noise level perceived indoors through an acoustic window depends, apart from the outdoor noise level, on the volume of void created between two window panes, the area formed by the gap width and window height, as well as the outer window opening area. However, it is noted that the limitations of the current regression where some other factors which are supposedly to have contributing factors were not considered. The current finding is considered rather preliminary but hopefully, more measurement tests will be conducted to verify the findings and include more contributing factors in the empirical model.

## Appendix

Table A1. Summary of Relative Noise Reduction of Acoustic Window in 33 Sets of Mock-up Test and Lab Test.

| No. | Ref. | ID | Internal Floor Area (m²) | Conventional Window Height (mm) | Conventional Window Width (mm) | Acoustic Window Height (mm) | Acoustic Window Outer Window Width (mm) | Acoustic Window Inner Window Width (mm) | Acoustic Window Overlapping Length (mm) | Acoustic Window Gap Width (mm) | Orientation (Degree) | Elevation (Degree) | Conventional Window Corrected Outdoor Noise Level dB(A) | Conventional Window Corrected Indoor Noise Level dB(A) | Conventional Window Traffic Noise Spectrum Correction dB(A) | Conventional Window Actual Noise Reduction dB(A) | Acoustic Window Corrected Outdoor Noise Level dB(A) | Acoustic Window Corrected Indoor Noise Level dB(A) | Acoustic Window Traffic Noise Spectrum Correction dB(A) | Acoustic Window Actual Noise Reduction dB(A) | RNR, dB(A) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 1 | 8 | 870 | 580 | 1385 | 870 | 840 | 100 | 100 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 82.1 | 66.9 | -1.1 | 14.1 | 4.3 |
| 2 | | 2 | 8 | 870 | 580 | 870 | 600 | 840 | 100 | 100 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 82.8 | 64.9 | -1.5 | 16.4 | 6.6 |
| 3 | | 3 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 30 | 30 | 83.2 | 72.2 | -0.4 | 10.6 | 83.1 | 63.2 | -2.1 | 17.8 | 7.2 |
| 4 | | 4 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 60 | 30 | 82.7 | 70.7 | -1.1 | 10.9 | 83.7 | 64.3 | -1.7 | 17.7 | 6.8 |
| 5 | | 5 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 90 | 30 | 82.5 | 71.1 | -1.4 | 10 | 83.6 | 65.7 | -2.2 | 15.7 | 5.7 |
| 6 | 21 sets of | 6 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 120 | 30 | 84.9 | 70.9 | -1.2 | 12.8 | 84.6 | 66.7 | -1.1 | 16.8 | 4 |
| 7 | Mock-up | 7 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 150 | 30 | 85.6 | 72.1 | -0.5 | 13 | 85.2 | 63.8 | -1.1 | 20.3 | 7.3 |
| 8 | Test | 8 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | -30 | 30 | 83 | 73.6 | -0.4 | 9 | 82.9 | 65 | -0.6 | 17.3 | 8.3 |
| 9 | (Manuscript | 9 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | -60 | 30 | 83.1 | 73.9 | -0.1 | 9.1 | 83.5 | 66 | -0.7 | 16.8 | 7.7 |
| 10 | Section 3.1 | 10 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | -90 | 30 | 83.7 | 73.9 | -0.4 | 9.4 | 83.8 | 67 | -1 | 15.8 | 6.4 |
| 11 | refers) | 11 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | -120 | 30 | 83.7 | 73.2 | -0.9 | 9.6 | 84.7 | 68.1 | -0.8 | 15.8 | 6.2 |
| 12 | | 12 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | -150 | 30 | 84.8 | 70.4 | -0.9 | 13.5 | 85 | 65.7 | -0.5 | 18.8 | 5.3 |
| 13 | | 13 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 0 | 60 | 83.7 | 72.3 | -0.7 | 10.7 | 82.7 | 64.6 | -1.3 | 16.8 | 6.1 |
| 14 | | 14 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | 150 | 60 | 84.1 | 69.1 | -1 | 14 | 84.9 | 65.3 | -0.9 | 18.7 | 4.7 |
| 15 | | 15 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 100 | -150 | 60 | 84 | 69.7 | -1 | 13.3 | 84 | 67 | -0.8 | 16.2 | 2.9 |
| 16 | | 16 | 8 | 870 | 580 | 870 | 600 | 580 | 300 | 100 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 82.9 | 65.5 | -1.2 | 16.2 | 6.4 |
| 17 | | 17 | 8 | 870 | 580 | 870 | 600 | 580 | 500 | 100 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 82.9 | 65.6 | -1.5 | 15.8 | 6 |
| 18 | | 18 | 8 | 870 | 580 | 870 | 600 | 580 | 100 | 175 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 81.8 | 66.6 | -0.1 | 15.1 | 5.3 |
| 19 | | 19 | 8 | 870 | 580 | 870 | 600 | 580 | 300 | 175 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 82.4 | 66.3 | -0.4 | 15.7 | 5.9 |
| 20 | | 20 | 8 | 870 | 580 | 870 | 600 | 580 | 500 | 175 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 83.5 | 66.8 | -1.2 | 15.5 | 5.7 |
| 21 | | 21 | 8 | 870 | 580 | 870 | 770 | 750 | 100 | 100 | 0 | 30 | 83.1 | 72.9 | -0.4 | 9.8 | 83.1 | 66.4 | -2.3 | 14.4 | 4.6 |
| 22 | | 1 | 21 | 1350 | 430 | 1350 | 320 | 320 | 100 | 145 | 0 | 15 | 89.8 | 81.7 | N/A | 8.1 | 90.2 | 71.5 | N/A | 18.7 | 7.9 |
| 23 | | 2 | 21 | 1350 | 430 | 1350 | 320 | 320 | 700 | 205 | 0 | 15 | 89.8 | 81.7 | N/A | 8.1 | 87.2 | 70 | N/A | 17.2 | 7.1 |
| 24 | | 3 | 21 | 1350 | 430 | 1350 | 320 | 320 | 100 | 145 | 0 | 15 | 89.8 | 81.7 | N/A | 8.1 | 90.3 | 70.6 | N/A | 19.7 | 8.1 |
| 25 | 12 sets of | 4 | 21 | 1350 | 430 | 1350 | 320 | 320 | 700 | 205 | 0 | 15 | 89.8 | 81.7 | N/A | 8.1 | 90.2 | 72.1 | N/A | 18.1 | 8.1 |
| 26 | Lab Test | 5 | 21 | 1350 | 600 | 1350 | 600 | 600 | 100 | 145 | 0 | 15 | 89.8 | 83.6 | N/A | 6.2 | 90.2 | 72.7 | N/A | 17.5 | 9.5 |
| 27 | (Manuscript | 6 | 21 | 1350 | 600 | 1350 | 600 | 600 | 700 | 205 | 0 | 15 | 89.8 | 83.6 | N/A | 6.2 | 90.3 | 74.7 | N/A | 15.6 | 8.6 |
| 28 | Section 3.2 | 7 | 21 | 1350 | 600 | 1350 | 600 | 600 | 300 | 145 | 0 | 15 | 89.8 | 83.6 | N/A | 6.2 | 89.8 | 71.6 | N/A | 18.2 | 9.9 |
| 29 | refers) | 8 | 21 | 1350 | 600 | 1350 | 600 | 600 | 700 | 205 | 0 | 15 | 89.8 | 83.6 | N/A | 6.2 | 90.5 | 73.2 | N/A | 17.3 | 9.2 |
| 30 | | 9 | 21 | 1350 | 1130 | 1350 | 950 | 950 | 300 | 145 | 0 | 15 | 89.8 | 85.1 | N/A | 4.7 | 89.8 | 73.6 | N/A | 16.2 | 9.9 |
| 31 | | 10 | 21 | 1350 | 1130 | 1350 | 950 | 950 | 700 | 205 | 0 | 15 | 89.8 | 85.1 | N/A | 4.7 | 89.8 | 75.7 | N/A | 14.1 | 9.4 |
| 32 | | 11 | 21 | 1350 | 1130 | 1350 | 950 | 950 | 300 | 145 | 0 | 15 | 89.8 | 85.1 | N/A | 4.7 | 89.9 | 72.4 | N/A | 17.5 | 11.1 |
| 33 | | 12 | 21 | 1350 | 1130 | 1350 | 950 | 950 | 700 | 205 | 0 | 15 | 89.8 | 85.1 | N/A | 4.7 | 89.7 | 74 | N/A | 15.7 | 10.5 |

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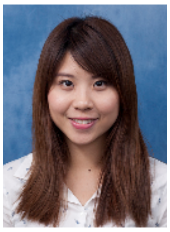

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