RESEARCH INTO THE ACOUSTIC TRANSMISSION OF OPEN AND CLOSED WINDOWS

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1. INTRODUCTION

The continuing trend of the house-building sector for high density development on urban brown-field sites follows policy outlined by the Office of the Deputy Prime Minister's Planning Policy Guidance document 3, Housing(PPG 3)[1]. PPG 3 commits to sustainable patterns of development through the concentrated use of previously developed land within the urban environment, whilst ensuring that homes are decent, well designed and improve the quality of life.
Housing in an urban environment however has a greater potential for environmental noise issues compared to suburban or rural developments. Acoustic suitability of residential site applications are primarily assessed according to the external noise environment determined from survey and assessed against the Noise Exposure Categories, advocated in PPG 24, Planning and noise[2] and Planning Advice Note 56 (PAN 56)[3]. Where further evidence is requested or where a specific acoustic planning condition needs to be demonstrated, it is usual to consider the potential development in greater detail through predictions of internal noise levels. The means of that prediction can however be open to significant variation, depending on the calculation method employed, site geometry assumptions and the definition of acoustic façade performance considered.
The range of façade specifications requested by Local Authority imposed planning conditions are highlighted in the following examples taken from urban residential planning applications subject to different sources of noise. The first makes no requirement for the façade, although the second specifically requires that predictions be undertaken allowing for closed window conditions whilst the third specifically request that an open-window prediction be undertaken. The form of text are reproduced here:

- Internal noise levels … shall not exceed 45 dB $L_{Aeq(16hrs)}$ during the day and 35 dB $L_{Aeq(8hrs)}$ during the night.
- … road traffic noise does not give rise to an internal $L_{10(18\ hour)}$ level of more than 40 dB(A), (windows closed) …
- … noise levels associated with the nearby electricity sub station comply with NR20 within the said living apartment, with a window open for ventilation.

This paper provides the initial findings from a study undertaken by the Building Performance Centre at Napier University. The project, an investigation into the acoustic transmission loss characteristics of open windows, was instigated by the Department for Food and Rural Affairs (Defra) to provide clear and unambiguous guidance for use in façade break-in noise predictions, assuming the façade incorporates means for passive ventilation. Initial stages of the study were spent undertaking a literature review of published measurement data. Subsequent stages have concentrated on the design, set-up, execution and analysis of a laboratory measurement programme. The scope of the study necessitated a free-field source environment to enable consideration of source directivity and to improve simulation of field conditions. The receiving room was designed to approximate conditions typically found in an unfurnished domestic bedroom.

2. BACKGROUND

2.1 Role Of Noise Planning Guidance

Planning guidance documents are required to advise on the suitability of development with consideration to both the existing characteristics of the locale and future residential amenity. In a noise context, advice is necessary to define threshold exposure levels relative to extraneous sources of environmental noise against which the suitability of a site and development proposal can be compared.

Designers of residential developments are often forced to work around acoustic site constraints which are not satisfactorily overcome by the use of acoustic barriers, e.g. raised transport corridors, high rise developments or close proximity noise sources. In these situations it is the building envelope, principally through the exposed windows and ventilators, that are required to make up any insulation shortfall. Whilst the measures required to upgrade the acoustic insulation characteristics of a façade are well understood, i.e. sealing penetrations, increasing surface mass and providing panel isolation, they all have a detrimental impact on the passive supply of fresh air.

The mechanisms for natural ventilation through a façade are fundamentally opposed to the principles required to achieve high levels of sound insulation. Natural ventilation is however the preferred option for new build residential developments, primarily because of its economic and sustainability advantages; derived from the low manufacturing and installation costs and independence from maintenance requiring, space-taking, expensive mechanical plant.

2.2 Open Window Insulation

Advice on the sound insulation characteristics of windows and ventilators are limited. Advice is constrained to simplistic assessments performed under non-general test conditions and with consideration to only a restricted numbers of window styles and test parameters. Furthermore results are provided in a range of sound insulation indices which are not readily comparable. Table 1 summarises available advice and peer-reviewed reports that explicitly consider the sound transmission characteristics of open windows.

Table 1. Review Summary of open-window acoustic transmission Literature

Information Source	Summary of Findings
PPG 24 (1994) [2]	A reduction of 13 dB(A) from the facade level is assumed for an open window.
WHO (1999) [4]	A reduction of 15 dB from the facade level is assumed for a partially open window. (no reference)
BS 8233 (1999) [5]	Windows providing rapid ventilation and summer cooling are assumed to provide 10 - 15 dB attenuation (no specific reference).
BRE Digest 338 (1988) [6]	A partly open window has an averaged level difference, $D_{1m,av100\text{-}3150}$ of 15 dB
DoE Design Bulleting 26 (1972) [7]	A reduction of 5 dB(A) with a window wide open
Transportation Noise Reference Book (1987) [8]	Sound insulation of an open single window is 5 – 15 dB. (theoretical)
Heriot Watt University (1972 – 73) [9], [10]	A vertical sliding sash window open 0.027 m^2 (summer night-time ventilation) and 0.36 m^2 (daytime summer ventilation) provided a sound level reduction of 16 and 11 dB(A) respectively. (Lab Study)
Kerry and Ford (1973 – 74)[11], [12]	A horizontal sliding sash window open 25 mm and 200 mm provided averaged sound reduction indices, R_{av} of 14 and 9 dB respectively. (Field Study)
Lawrence and Burgess (1982 – 83) [13][14]	A vertical sliding sash open 9% of the total façade provided a sound reduction index R_w 10 dB. (Field study)
Hopkins (2004) [15]	Road traffic noise reductions through window openings resulted in reductions of between $D_{2m,n,T}$ 8 and 14 dB. (Field Study)

2.3 BACKGROUND VENTILATION

The use of openable windows as the defined source of ventilation are frequently substituted in noise sensitive developments for acoustically treated air transfer devices located within the façade, window or more commonly the window frame. Acoustic treatment of ventilator products typically involves a combined approach of increased path tortuosity and added passive or reactive absorbers. An extensive review of noise control strategies used in passive ventilation systems is provided by De Salis et al[16]. The overall effect however is to increase the flow resistance of the system, thereby reducing ventilation efficiency. This performance reduction is not however currently addressed by the Building Standards Regulations [17] which specifies background ventilation in terms of the openable free area of the air flow path. A change is however proposed [18]with a move away from the geometric requirement to an air-flow performance, 'equivalent area' specification.
The ventilation requirements of the Building Standards Regulations are broadly similar across the UK, excepting the draft 2006 revision for England and Wales. The primary motivation for the change from the prescriptive 1995 edition to the performance based proposals is the principal policy of reducing ventilation heat loss whilst still enabling adequate indoor air quality. Thermal improvements are to be effected through improvements in the air-tightness standard of the overall build [19], such that uncontrolled leakage through the building fabric are reduced in favour of controlled, device based ventilation.
The standard method of measuring the equivalent area for an air transfer device, derived from its air-flow performance at 1 Pa pressure difference, is given in BS EN 13141-1 [20], however as an approximation, the draft ADF advises that the free area of a trickle ventilator is typically 25% larger than its equivalent area. The level of passive background ventilation required to meet the draft ADF is calculated for the whole dwelling taking account of the floor area, no. habitable rooms and height characteristics. The minimum requirement for the 'System 1' ventilation strategy (background ventilation with intermittent wet area extract fans) is an equivalent ventilation area of 5000 mm^2 per

room. The equivalent current regulations allow a minimum openable free area of background ventilation of 4000 mm^2 per room.

3. EXPERIMENTAL TECHNIQUE

3.1 Laboratory Conditions

The laboratory setup followed the requirements of BS EN ISO 140 parts 1[21] and 3[22] as far as was reasonably practicable given the project requirement of a free-field source room and a reverberation controlled receiver room. The laboratories at Heriot-Watt University were utilised for the research programme, specifically the structurally isolated 300 m^3 anechoic chamber and adjacent 210 m^3 reverberation chamber; separated by a demountable partition and a 12 m^2 test aperture.

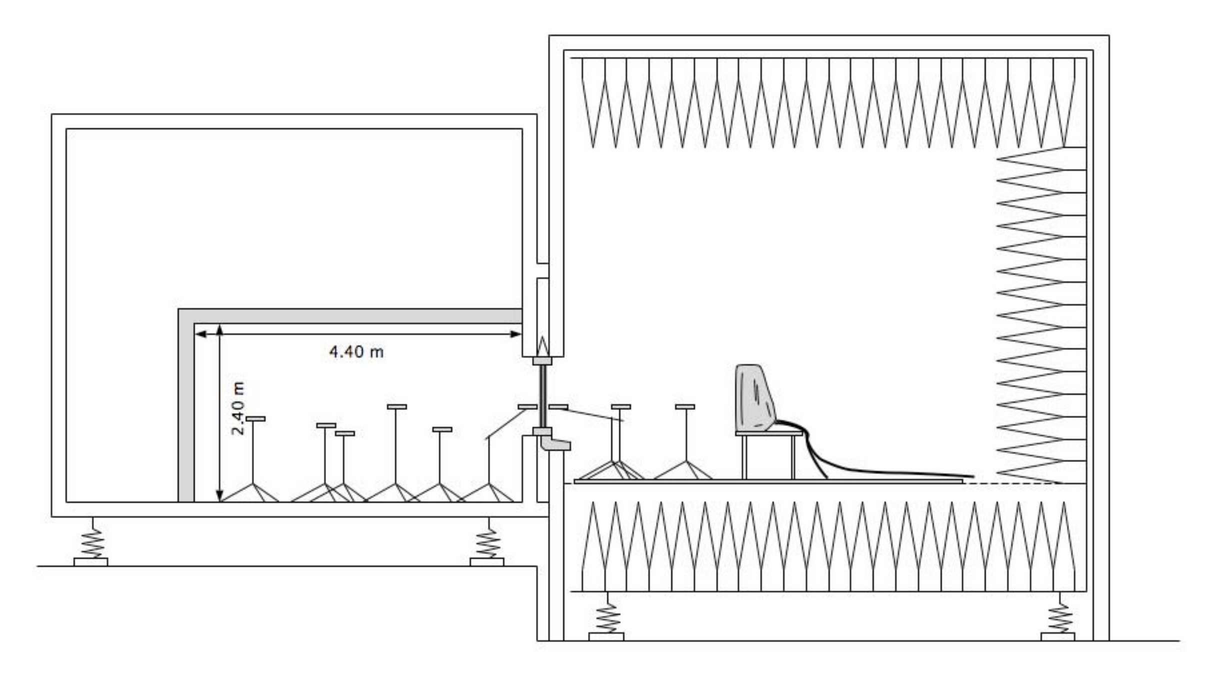


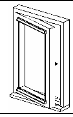
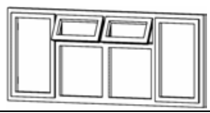
Figure 1. Section through experimental set-up

Initial laboratory preparation works required the removal of the demountable separating components including the anechoic wedges to a height of 4 m across the full width of the separating wall and the construction of a domestic sized receiver room within the reverberation chamber. The test room was constructed using a timber frame lined with plasterboard. The internal dimensions of the constructed receiver room were 4.4 m x 3.6 m x 2.4 m. A cavity masonry separating wall consisting of 100 mm dense concrete block, 50 mm cavity, 100 mm dense concrete block with a plasterboard lining on timber straps was built as a filler wall within the test aperture between the source and receiver test rooms. A range of seven test windows were installed into the filler wall throughout the test regime.

3.2 Window Samples

The selection of test windows were based on survey replies from window manufacturers asked to consider their most popular residential frame material, style and sealing system. Details of the window samples used in the programme are summarized in Table 2. The glass specification fitted into each test sample was a thermally sealed double glazed unit with a 4 – 16 – 4 mm specification. Only frame 6 was fitted with a trickle ventilator slot.

Table 2. Summary of window samples used in experimental study

Sample Identifier	Window Type	Frame Size (mm)	Frame	Weight (kg)	Opening Style	Indicative Sketch
1	Top Hung 'London'	600 x 1050	70 mm PVCU	16.9	Top hinged top light	
2	Top Hung 'London'	600 x 1050	48 mm Aluminium	16.9	Top hinged top light	
3	Side Hung	600 x 900	94 mm Timber	18.0	Side hung, external opening	
4	Reversible	1200 x 1050	70 mm PVCU	35.2	Horizontal sliding pivot	
5	Multi-Unit	2400 x 1050	60 mm PVCU	75.6	A Side hung (LHS) B Top Lights C Side hung (RHS)	
6	Tilt & Turn	900 x 1050	70 mm PVCU	29.2	A Internal Tilt B Internal Side Hung	
7	Sliding Sash	900 x 1200	135 mm PVCU	34.8	A Vertical (lower) B Vertical Higher) C Internal Tilt (Lower)	

3.3 Measurement Equipment

Source signal generation and data acquisition was performed with a software controlled nine-channel B&K "*Pulse*" measurement system. The excitation signal was a 30 second, 50 Hz to 5 kHz pink noise. The signal was fed to an active loudspeaker set normal to the façade, at a horizontal distance of 2.72 m from the filler wall and at a height of 1.2 m. Source microphones were located at three positions between the centre of the test window and the acoustic centre of the loudspeaker at the test window, 1 m from the test window and 2 m from the test window. Five distributed microphones were used to characterise the noise level within the receiver room.

4. RESULTS

4.1 Open window results

The results of the laboratory measurement are presented here as single figure weighted level differences relative to the source microphone located at the centre of the test window and averaged receiver room microphones. The weighting has been performed in accordance with BS EN ISO 717-1 [23] for each one-third octave level difference spectrum, for an unfurnished room with a mid-frequency reverberation time of approximately 1.5 s.
The effects of varying the opening size for the seven windows tested, with the opening permutations outlined in Table 2, are shown in Figure 2. Each opening style is compared under three open free-area conditions, calculated as closely as possible to 50 000 mm², 100 000 mm² and 200 000 mm².

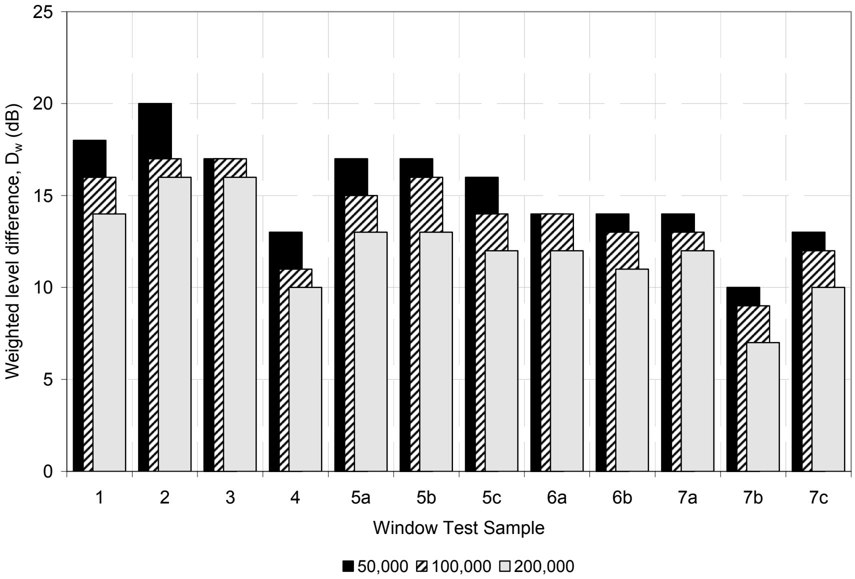


Figure 2. Level Difference Measurement Results, D_w. Windows opened 50 000, 100 000 and 200 000 mm^2.

General comments of these results are:

The largest open area provides the least resistance to sound, however two opening styles (sample 3 and 6a), show negligible difference between the smallest two openings considered.

Differences of 10 dB have been measured across all window styles for an open window area of 50 000 mm². The best performing opening was a small top opening light, whilst the worst was a vertical sliding sash.

The average difference, across the range of window samples, between the smallest (50 000 mm²) and largest (200 000 mm²) open positions is 3 dB.

The reduction in acoustic insulating performance was greatest for the change in open window area between 100 000 mm² to 200 000 mm² than between 50 000 mm² to 100 000 mm².

4.2 Ventilator Results

The results shown here correspond to window sample 6 fitted sequentially with five trickle ventilators and their appropriate external canopy with open areas between 4000 mm^2 and 4400 mm^2. Also compared to these results in Figure 3 are the results when the ventilator aperture was securely blocked with plasterboard and mastic, with no treatment applied to the aperture and also with the window 'tilted' open 50 000 mm^2. The size of the untreated aperture was 4500 mm^2**.**

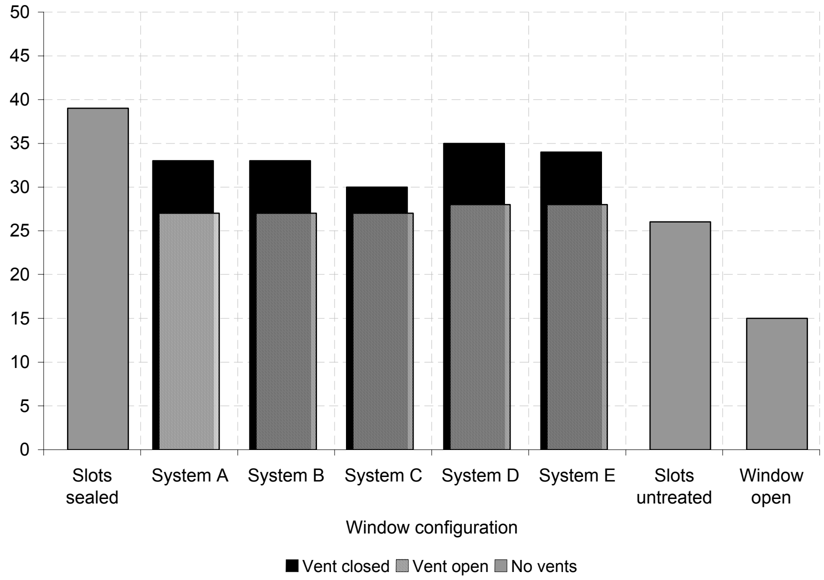


Figure 3. Level Difference Measurement Results, D_w. Comparison of performance of 4000 mm^2 trickle vent systems.

The main conclusions drawn from the ventilator measurement results are that:

The inclusion of a slot ventilator within the window frame, even in the closed position will significantly affect the sound insulation of the window.

In the open position, the ventilators perform only marginally better than the open untreated aperture condition.

There is a very consistent performance across each trickle vent product when it is open for ventilation.

Insulation performance with the single ventilator fitted is 10 dB better than that achieved with the window open 50 000 mm^2.

5. REFERENCES

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