VENTILATIVE COOLING IN NOISY ENVIRONMENTS: PRACTICAL OPTIONS FOR THE UK

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1 ABSTRACT

It is only very recently that a proper consideration of the internal acoustic environment when mitigating overheating has started to be taken seriously in the UK. Previously this issue has not been addressed by the various regulatory systems, and developers have been reluctant to pay for what they have seen as an unnecessary consideration. The Association of Noise Consultants has produced the criteria and guidance in its draft Acoustics, Ventilation & Overheating: Residential Design Guide. At this crucial stage in the establishment of new approaches for the construction industry, we are setting out "rules of thumb" with typical options for ventilative cooling in varying external noise environments. We are developing solutions in collaboration with mechanical engineers and product manufacturers that are suitable for UK building typologies. Vents in the external facade are found to present the easiest adoption into current building designs. As acoustic attenuation typically involves airflow resistance, mechanical fans are required to ensure ventilation rates are achieved in noisier environments or where the apartment has single-sided ventilation opportunities.

2 INTRODUCTION

The need to mitigate overheating in modern dwellings can require ventilation rates much greater than the rates requires to simply provide reasonable air quality. The provision for purge ventilation, usually opening windows, is typically relied upon for this purpose. However, high noise levels are frequently cited as a reason that residents are reluctant to open windows to provide increased ventilation, and they may suffer from over-heating as a result. The regulatory framework in the UK does not currently require noise and overheating requirements to be considered together and this has led to the situation where the majority of planning application include noise assessments based on closed windows and overheating assessments which assume that the windows are open, as described by Conlan et al [1].

This paper presents practical methods to provide ventilation rates that may be suitable to mitigate over-heating using façade mounted ventilation systems and compares the performance with open windows. Other methods such as good acoustic design for the building location and orientation, the use of balconies or enhanced window configurations can also reduce the noise ingress to the building; these are discussed by Conlan et al [2,3].

3 AVO GUIDE

The Association of Noise Consultants has produced the draft Acoustics Ventilation and Overheating (AVO) Residential Design Guide [4]. The AVO Guide recommends an approach to acoustic assessment that takes regard of the interdependence of provisions for ventilation to mitigate overheating with external noise ingress. It provides guidelines for indoor ambient noise levels during the time periods when cooling may be required, and the proposed levels are higher than the generally accepted annual-average noise levels on the basis that only occur part of the year. This is based on an assumption of "adaptive acoustic comfort" as described by Harvie-Clark et al [5] - where occupants may exercise control over the internal environment by opening windows, for example.

4 VENTILATIVE COOLING

4.1 Definition

Ventilative cooling is a way to cool indoor spaces through the use of natural (passive) ventilation, mechanical ventilation strategies or a combination of both. Ventilative cooling uses outside air to remove heat from indoor spaces to mitigate overheating. Ventilative cooling can save cooling energy and gives more flexibility and design options for buildings, enabling a broader range of design solutions to fulfil building energy legislations [6]. Ventilative cooling aims to cool a dwelling without using coolants, which are typically referred to as air conditioning systems.

4.2 Natural Ventilation Options

In its simplest form, ventilative cooling would be the opening of a window to allow cooler external air to reduce the internal temperature. For noisy environments an attenuated ventilator could be used to provide a similar airflow as an open window. The efficiency of the natural ventilation can be influenced by design decisions such as the opening dimensions, the number of openings and their position in a building e.g. is it single sided ventilation, or can the dwelling be ventilated by openings on more than one façade – cross flow ventilation. In addition to the design influence, the air flow at any one time will be determined by variable uncontrolled factors which are the wind speed, wind direction and temperature difference between outside and inside of the building.

4.3 Mechanical ventilation and hybrid options

A full mechanical ventilation system would consist of a fan unit within the dwelling which is ducted to the building facade to bring air into the dwelling with a separate duct for the exhaust air. For a mechanical extract system the air usually enters the building via a façade mounted ventilator and would be extracted mechanically by a fan. In the UK these systems would typically be referred to as MVHR and MEV systems respectively.

The advantages of using a mechanically assisted system is that the airflow rate can be controlled by the fan and is not subject to external factors. Façade air inlets can be much smaller as the pressure differences induced by the fan can be much greater than the natural pressure differences from ambient conditions. The disadvantages are that the system would use energy compared to a natural ventilation system and that the system is likely to require greater maintenance during the lifetime of the building.

5 VENTILATION OPENING TERMINOLOGY

5.1 Single openings

There is much confusion regarding the terminology used to describe ventilation openings; the proposed definition used here are taken from Jones et al [7]. A sharp-edged orifice is a circular opening with unsmoothed edges and a length that is significantly shorter than its diameter. The airflow rate, Q (m^3/s), through and sharp edged opening is proportional to its cross sectional area, often referred to as a free area, A_f (m^2). It is also a function of the pressure drop across the opening ΔP (Pa), the density of the air ρ (kg/m^3) and geometry of the opening such that:

$$Q = C_d \, . \, A_f \, . \sqrt{(2 \, \Delta P / \rho)} \tag{1}$$

Where Cd is the discharge co-efficient used to account for the restriction to the airflow for different opening types, and for a circular sharp-edged orifice Cdo = 0.61. In practice the use of free areas lacks definition and can lead to different estimates. In Approved Document F it is described as the geometric open area of a ventilator The discharge coefficient Cd of a window can be estimated using a spreadsheet, based on measured data, and with variables for the windows dimensions and degree of opening, as described by Daniels et al [8].

5.2 Equivalent and Effective areas

The equivalent area, A_{eq}, is a measure of the aerodynamic performance of the ventilator and is defined as the area of a sharp-edged orifice which air would pass through at the same flow rate for the same pressure difference as the opening under consideration. The air flowing through the orifice is still restricted by the discharge coefficient of the orifice. It can be represented by the equation:

$$A_{eq} = C_d \, . \, A_f \, / \, C_{do} \qquad (2)$$

The effective area, A_{eff}, (or net area) is also a measure of the aerodynamic performance and is represented by the equation:

$$A_{eff} = C_d \, . \, A_f \qquad (3)$$

The effective area is considered the most useful parameter for defining the aerodynamic performance of a ventilation opening.

6 ACOUSTIC PERFORMANCE OF VENTS

6.1 Individual Vents

The acoustic performance of vents are given as the element normalized level difference, $D_{n,e,}$ and is expressed in decibels (dB).The performance is measured in a laboratory following the methodology of BS EN ISO 10140 [9] and calculated using equation (4).

$$D_{n,e} = L1 – L2 – 10 \lg A / A_0 \text{ dB} \quad (4)$$

For unsilenced air inlets, such as a simple opening or weather louvre in the façade, the value can be calculated using the following equation as described in BS EN 12354-3 [10]:

$$D_{n,e} =- 10 \log (S_{open} / 10) \qquad (5)$$

Where S_{open} is the area of the opening in m^2.

As the performance is based on a single vent, if more than one vent is used in a façade then the internal noise will increase as additional sound energy will enter the building. For more than one vent with the same acoustic performance, $D_{n,e}$, the performance of N number vents is:

$$D_{n.e}(N) = D_{n,e} – 10 \lg N \qquad (6)$$

7 PASSIVE VENTILATION OPTIONS

7.1 Comparison of open windows and attenuated vents

To compare the acoustic performance of an attenuated vent with an open window it is necessary to determine the equivalent ventilation performance of each. For this comparison we compare a square façade opening with the physical open area of 1 m^2. Assuming a coefficient of discharge, C_d, for the opening of 0.62, the opening has an effective area, A_{eff}, of 0.62 m^2. For comparing acoustic vents and open windows on this basis the effective area of the element (vent or open window) should also be 0.62 m^2. An open window which has the same effective area would typically be 1.5 m wide, 1.15 m height and opened to 25 degrees, giving a 0.5 m throat opening.

We have compared test data for commercially available vents, which have both acoustic and ventilation performance data. The tested vents have a face area of 1.8 m^2 and consist of an external weather louvre, an attenuator and an internal damper (tested separately for the acoustic tests).

7.2 Acoustic ventilator performance

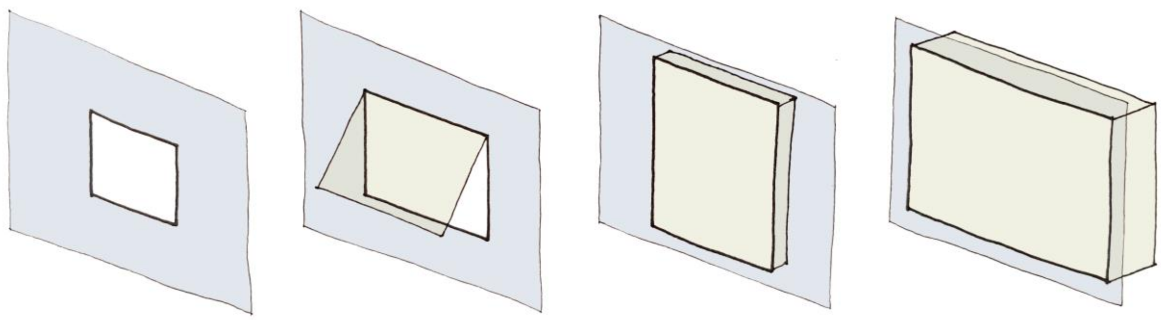
For each tested acoustic ventilator, the effective area of the unit and therefore the total area of ventilator required to achieve the same effective area as the 1 m^2 opening, has been calculated. The acoustic performance of the ventilator is adjusted to account for the area of the vent using equation (6). The resulting acoustic performance for each of the tested acoustic vents is shown Table 1.

Table 1 – Acoustic performance of attenuated vents with an effective area of 0.62 m^2

Vent Description	Effective Area m^2	No. vents required to achieve 0.62 m^2 A_{eff}	$D_{n,e,w} + C_{tr}$ one vent	$D_{n,e,w} + C_{tr}$ for vents with A_{eff} = 0.62 m^2
1 m^2 opening	0.62 m^2	1 m^2	10	10
600 mm long 41% OA	0.2	3.03	24	19
600 mm long 24% OA	0.14	4.36	30	24
300 mm long 41% OA	0.26	2.39	20	16
300 mm long 24% OA	0.15	4.16	24	18
150 mm long 41% OA	0.26	2.37	16	12
150 mm long 24% OA	0.20	3.08	20	15

A summary of the dimensions and acoustic performance of a simple opening, open window and attenuated vents, which provide the same ventilation performance, is shown in Table 2.

Table 2 – Comparison of window and attenuated vents required to provide the same effective area, 0.62 m^2



1 m^2 opening	1.5 m x 1.15 m window open at 25° [varies]	1.8 m x 2.2 m x 0.15 m attenuator	2 m x 2.6 m x 0.6 m attenuator
$D_{n,e,w} + C_{tr}$ 10 dB		$D_{n,e,w} + C_{tr}$ 15 dB	$D_{n,e,w} + C_{tr}$ 19 dB

The values of acoustic performance against the size of the attenuators has been plotted to establish the relationship between the volume of the attenuator and the required acoustic performance. An estimate of the required volume for an attenuator, V, for a given acoustic performance and effective area can be made using:

$$V, m^3 = [((D_{n,e,w} + C_{tr}) - 12.9) / 2.27] . [A_{eff} / 0.62] \qquad (7)$$

The estimated volume doesn't include the space required for louvres, filters or dampers and is just for the attenuation element.

8 COMPARISON OF OPEN WINDOWS

8.1 Napier University Study

A study of the sound insulation through ventilated domestic windows [11] gives the acoustic performance of different window types opened to provide different free areas. As overheating control generally requires larger window openings compared to ventilation rates for air quality, only the largest tested free area of 0.2 m^2 has been assessed.

The effective area for each window type has been calculated using Daniels [8] and the measured acoustic performance has been adjusted based on the area required to provide an effective area of 0.62 m^2. The predicted acoustic performance for each of the window types is shown in Table 3.

Table 3 – Comparison of window acoustic performance to provide the same effective opening

Window reference	Glazed Area m^2	Effective area m^2	$D_{new} + C_{tr}$ dB	$D_{new} + C_{tr}$ for windows with $A_{eff} = 0.62 m^2$
A1 – Side hung	0.45	0.124	17	10
A2 – Top hung	0.15	0.133	15	8
C – Tilt and Turn	0.71	0.120	17	10
D – Sliding Sash	0.45	0.106	15	7
E – Top hung	0.21	0.081	18	9
F – Top hung	0.28	0.093	18	10
G – Side hung	0.38	0.112	17	10

The predicted performances of the different window types are very similar, with the sash window being the poorest performing and potentially the small hinged windows performing slightly worse than the large windows. None of the windows performed better than the theoretical performance of a simple opening with an effective area of 0.62 m^2, which would be a 1 m^2 opening and a predicted $D_{n,e,w} + C_{tr}$ of 10 dB.

9 PREDICTED REQUIREMENTS FOR APARTMENTS

9.1 Overheating study for typical apartment design

Hilson Moran [12] have undertaken a detailed study of parameters which can influence the potential for overheating for a typical single bedroom apartment. They have compared the effects of glazing area, vent areas, single or dual aspect, orientation, internal and external shading and thermal mass. A typical arrangement of the rooms is shown in Figure 1 which shows both the single and dual aspect arrangements for the living room and bedrooms.

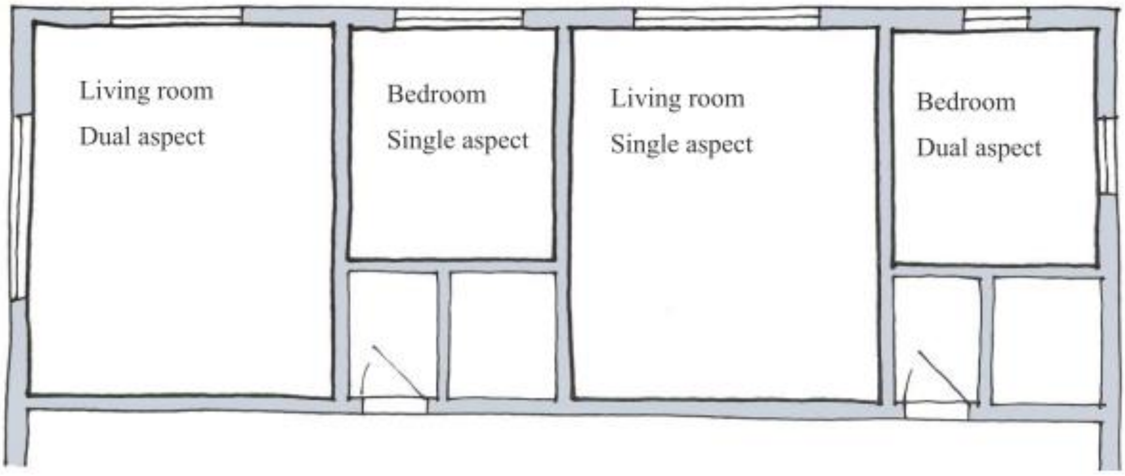


Figure 1: Arrangement of typical rooms modelled for overheating

For this assessment we are considering a design which does not incorporate measures to control overheating and has a glazed area equal to 40% of the façade area. This area has been used as the lowest modelled area which would be likely to achieve the desirable daylighting requirements for the apartments.

The analysis predicted the effective area required to achieve 'thermal comfort' – compliance with CIBSE TM 59 [13] - and for some orientations it is not possible to achieve this even with fully open windows. Dual and single aspect rooms were considered; dual aspect living rooms required larger open areas as the increased (solar gain) heat loads were not offset by the improved ventilation effectiveness. No living rooms achieved the thermal comfort criteria using open windows, apart from single aspect north facing rooms. For the bedrooms, thermal comfort criteria could be achieved with open windows; the effective areas required for different room orientations, single and dual aspects is shown in Table 4.

Table 4 – Effective area of façade opening to achieve thermal comfort in bedrooms of a notional London apartment with no overheating mitigation included

Aspect	Orientation	Effective area of ventilation openings to achieve thermal comfort m^2	Aspect	Orientation	Effective area of ventilation openings to achieve thermal comfort m^2
Single	N	1.84	Dual	E/N	1.39
Single	E	2.14	Dual	N/E	1.39
Single	S	2.45	Dual	E/S	2.09
Single	W	2.45	Dual	N/W	2.09

The lowest calculated effective area required is more than twice area of the vents and options shown in Table 2. Using equation (7), and for a $D_{n,e,w}$ of 18 dB, which could be suitable for external levels up to 55 dB $L_{Aeq,8hr}$ at night, the volume of the smaller ventilator for a dual aspect arrangement would be 5.0 m^3, or up to 20 % of the room volume.

Given that the living rooms cannot be controlled with natural ventilation and the large size of attenuation required for the bedrooms, natural ventilation appears to be impractical for controlling overheating in London apartments unless they incorporate overheating mitigation measures and / or mechanical assistance is used to increase the ventilation rates through the units.

10 HYBRID OPTIONS

As a natural system seems to be impractical for controlling overheating in London apartments, where noise levels exceed much above 50 dB $L_{Aeq,8hr}$ at night, a hybrid system could be considered which incorporates a façade mounted vent with an integrated fan to provide air flow.

10.1 Case Study

The refurbishment of a 26 story building, next to the A12 road in London, required a hybrid solution which had 0.12 m^2 free area vent for natural ventilation and an integrated fan which could provide the ventilation rates required to purge ventilate the rooms. The system provides 37 dB reduction from external to internal noise levels during operation and is fully controllable from switches within the bedroom. A sketch of the internal layout of the building is shown in Figure 2.

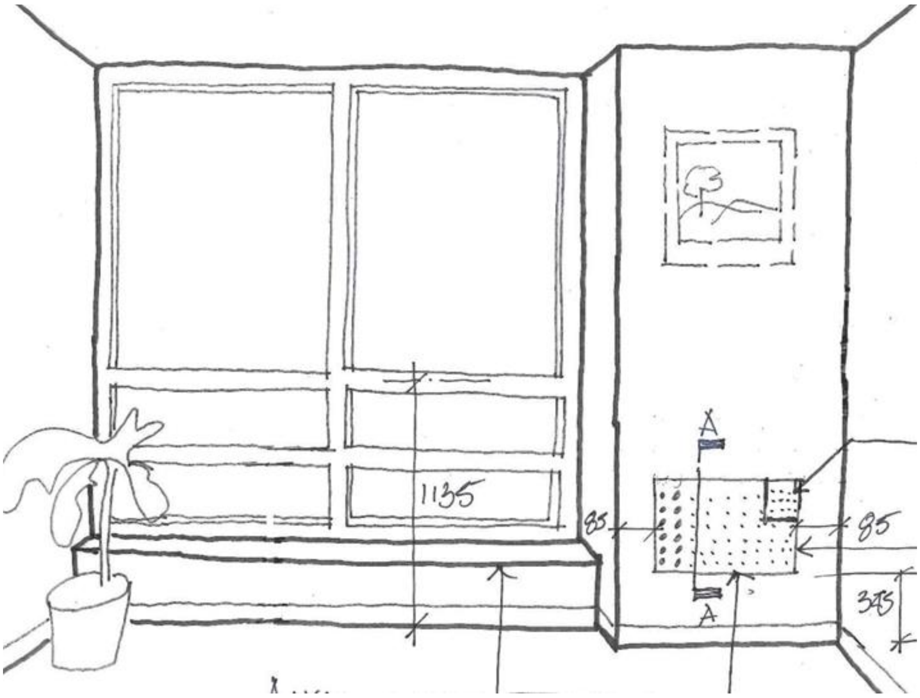


Figure 2: Interior view of attenuated hybrid vent (image courtesy of TEK Ltd)

11 CONCLUSIONS

The size of an attenuated ventilator which can provide the same ventilation performance as an open window can be estimated for a given sound reduction requirement using the equation (7). The overheating assessment of a typical London apartment with no particular overheating mitigation indicates that attenuated vents would need to be very large to have any significant control of noise ingress and may be impractical. Hybrid or mechanical systems for ventilative cooling are therefore likely to be more appropriate, unless the building includes appropriate overheating mitigation, or the aerodynamic performance of the vents can be significantly improved. Hybrid systems can be used to provide ventilative cooling; these systems can provide natural whole house ventilation, with fans providing increased ventilation rates for mitigating overheating.

12 ACKNOWLEDGEMENTS

The authors acknowledge the technical support for the overheating study from Hilson Moran and details of the acoustic and aerodynamic performance of the attenuated vents from TEK Ltd.

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