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# Natural ventilation and acoustic comfort

A. Chilton, P. Novo, N. McBride, A. Lewis-Nunes, I. Johnston and J. Rene

Max Fordham LLP, 42/43 Gloucester Crescent, Camden Town, NW1 7PE London, UK
a.chilton@maxfordham.com

Natural ventilation offers the potential for a sustainable, low-energy, low-maintenance solution to providing air to building occupants. When compared to mechanical ventilation systems, it also gives the benefits that occupants feel more connected with the outside world and perceive that they have better control over their environment. These are both factors that improve comfort and well-being. However, natural ventilation relies on larger openings in the façade which can create problems with the ingress of external noise that adversely affects occupant comfort. An overview is given as to how these conflicting issues can be resolved in the design process and several case studies making use of acoustically attenuated natural ventilation are presented. A methodology is proposed for comparing different attenuated ventilation elements using a quantitative rating based on a combination of both their aerodynamic and acoustic performance.

# 1 Introduction

## 1.1 Aims of ventilation

Buildings require ventilation in order to provide fresh air for occupant respiration and to remove $CO_2$, heat, moisture and other contaminants. For the purposes of this paper, natural ventilation is defined as ventilation that does not employ a mechanical driving force (i.e. a fan).

## 1.2 Advantages of natural ventilation

The advantages of natural ventilation result from the absence of fans. There is no fan energy requirement, no fan noise and no unwanted additional heat gain from the fan to the airstream. The low flow velocities also mean that air-flow noise is not significant. There is no requirement for plant space. There is a lower maintenance requirement and potentially lower capital and running costs.

In addition to this, occupants feel more connected with the outside world and perceive that they have better control over their environment.

## 1.3 Potential issues with natural ventilation

The main limitation is that natural ventilation relies on much lower driving pressures than mechanically driven systems. The driving pressure for buoyancy or wind driven natural ventilation is typically in the range 1-5Pa compared to the 100-500Pa that would be typical for mechanical ventilation.

The low driving pressure necessitates large openings that present little resistance to air-flow. Large openings in the façade can present an issue with noise ingress. For example, the sound insulation qualities of a partially open window are often cited as 10-15dB(A) [1] and the indoor ambient noise level requirement for naturally ventilated UK classrooms is $L_{Aeq,30min}$=40dB or less [2,3]. This implies that natural ventilation will potentially create problems with noise ingress on sites where $L_{Aeq,30min}$ exceeds 55dB, which would represent a large proportion of urban and sub-urban sites.

Another limitation of natural ventilation is that it is dependent on weather conditions (temperature/wind-speed), which are inherently variable and unpredictable. This means that it is harder to closely regulate natural ventilation, which can result in additional heat-losses during the heating season. There is also less potential for heat-recovery in natural ventilation systems. Recovering heat from exhaust air can reduce heat-losses during the heating season.

## 1.4 Acoustically attenuated natural vents

Acoustically attenuated natural vents require three main functional elements:

a) weather-proofing
b) acoustic attenuation
c) thermally insulated closing mechanism

There are a variety of ways in which these functions may be achieved. In some cases a single physical element may provide more than one of the functions, as illustrated by the following examples (in which the letters refer back to the functions described above):

- weather louvre (a), splitter attenuator (b), insulated door (c)
- window (a and c), acoustically lined plenum (b)
- weatherproof acoustic louvre (a and b), thermally insulated damper (c)

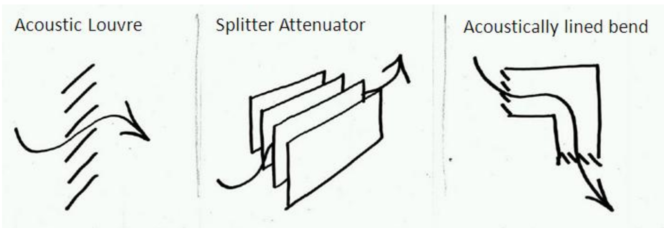


Figure 1: Types of acoustic attenuation.

For the purposes of this paper, the acoustic attenuation element is categorised as one of the following three types (shown schematically in Figure 1):

- Acoustic Louvre – angled, horizontal blades with a metal upper side and an acoustically absorbent underside. These are generally weatherproof to some extent.
- Splitter Attenuator – blades aligned with the airflow direction. The inside of the surrounding chamber and both sides of the blades are acoustically absorbent. These are the same as in-duct attenuators used in mechanical ventilation systems. Note that a lined, straight duct would be classified as a splitter attenuator with no splitters.
- Acoustically lined bend or plenum – any chamber or duct that has an acoustically absorbent lining and provides an offset or change-of-direction to the airflow path.

## 1.5 Design process

The design of acoustically attenuated vents needs to satisfy a number of independent requirements in terms of acoustic performance, aerodynamic performance, their physical appearance and integration with the building's façade.

The acoustic performance depends on the local external noise level and the target indoor ambient noise level. The aerodynamic performance depends on the ventilation design in terms of the available driving pressure and the required flow rate to provide fresh air and/or control overheating.

Acoustically attenuated vents often have a significant impact on the building's appearance and their development and integration needs to be coordinated by the architect.

As a result, the design of acoustically attenuated natural vents is an iterative, collaborative process responding to the specific needs of the site and the building. Figure 2 shows a schematic representation of the design process.

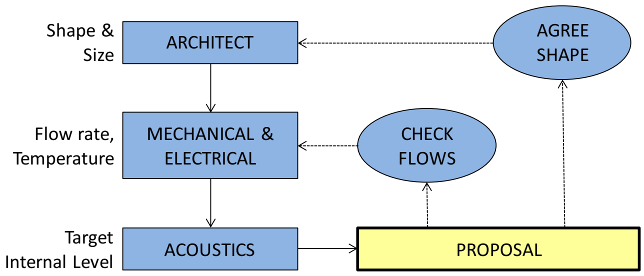


Figure 2: Design process for attenuated natural ventilation.

# 2 Ventilation Theory

The driving pressure for natural ventilation is created either by the effect of wind on the building or by the buoyancy of the warm air inside the building. Figure 3 shows the simple case of a room with ventilation openings on two sides.

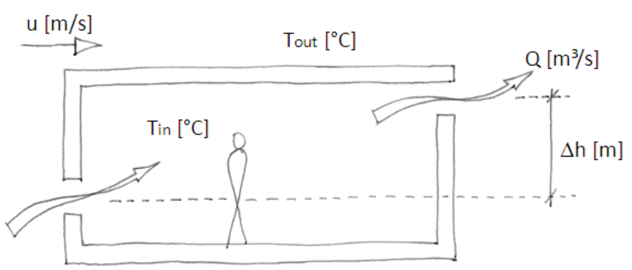


Figure 3: Naturally ventilated room with ventilation openings on two facades.

The driving pressure for natural ventilation, ΔP, follows the relationships below [4]:

- Wind Driven: $\Delta P \propto u^2$ (1a)
- Buoyancy Driven: $\Delta P \propto \Delta h.\Delta T$ (1b)

Where:

- u = wind speed [m/s]
- Δh = difference in heights of the two ventilation openings [m]
- ΔT = (Tin-Tout) = difference in internal and external temperatures [°C]

This pressure difference, which is typically in the range 1-5Pa, must drive the flow of air through both ventilation openings, so only part of the pressure difference is available to each opening.

The air flow rate through a window can be approximated by the following equation for fluid flow through a simple orifice [4]:

$$Q = C_d . A . \left(\frac{2.\Delta P}{\rho}\right)^{0.5} \qquad (2)$$

Where:

- Q = air flow rate [m³/s]
- ρ = density of air [kg/m³]
- A = area of the window opening [m²]
- ΔP = pressure difference across the orifice [Pa]
- $C_d$ = discharge coefficient for the opening [-]

The discharge coefficient has a value of 0.61 for a sharp edged, circular orifice. If additional components, such as acoustically attenuating elements, are added to a ventilation opening, they will restrict the airflow and the pressure loss associated with them must be accounted for. This can be done using the following expression [5]:

$$\Delta P = 0.5.\rho.\zeta.c^2 \qquad (3)$$

Where:

- c = air flow speed [m/s] = Q/A
- ζ = pressure loss factor [-]

Given that c=Q/A, comparison of Equations 2 and 3 reveals that a simple orifice can be regarded as a component with a pressure loss factor of $\zeta = (1/C_d)^2$.

The aerodynamic performance of ventilators is sometimes quoted in terms of an equivalent area [6]. The pressure loss factor for the component is related to the equivalent area as follows:

$$\zeta = 2.687.\left(\frac{A_{face}}{A_{equivalent}}\right)^2 \qquad (4)$$

Where:

- $A_{face}$ = face area of the ventilator [m²]
- $A_{equivalent}$ = equivalent area of the ventilator [m²]

Note that the pressure loss factors for individual components in series can be summed to find the total pressure loss factor, but only if each component can be considered aerodynamically independent of the others.

# 3 Quantitative Method for Comparing Ventilators

A comparison of acoustically attenuated ventilators must include a measure of their ability to attenuate noise break-in and the degree to which they restrict the airflow through the opening.

## 3.1 Aerodynamic Performance

The aerodynamic performance is quantified by a value termed the "reference area", $A_{ref}$. This is defined as the face area that the ventilator would need to have such that 1m³/s of air would flow through the vent at a pressure difference of 1Pa across the vent.

From Equation 3 and the definition, it can be seen that $A_{ref}$ is related to the total pressure loss factor for the ventilator as follows:

$$A_{ref} = (0.5.\rho.\zeta)^{0.5} \quad (5)$$

A lower value of $A_{ref}$ indicates a better performance.

## 3.2 Acoustic Performance

The acoustic performance is quantified here by the "reference level difference", $D_{ref}$, defined as:

$$D_{ref} = D_{n,e,w} + C_{tr} + 10.\log_{10}(A_{face}/A_{ref}) - 8.9\text{dB} \quad (6)$$

Where:

- $D_{n,e,w}$ is the element normalised level difference [7]
- $C_{tr}$ is the traffic spectrum correction [8]
- $A_{face}$ = face area of the ventilator [m²]

Note that the correction of 8.9dB is included so that a simple orifice opening, giving no sound reduction, has $D_{ref}$ = 0dB. By scaling the value of $D_{n,e,w}$ with the area of the ventilator, there is an implicit assumption that the acoustic properties are constant with size. This assumption will break down at small (relative to the sound wavelength) ventilator sizes, where effects such as end-reflections and edge-effects become significant. However, natural ventilation openings are generally relatively large and the approach described is considered to be reasonable. The traffic spectrum correction is included because the sites we have looked at are more commonly affected by traffic noise than other types of noise. A higher value of $D_{ref}$ implies a better performance.

## 3.3 Physical Size

The physical size of the ventilator is quantified here by the "reference volume", $V_{ref}$, defined as:

$$V_{ref} = A_{ref}.d \quad (7)$$

Where:

- d is the depth of the ventilator perpendicular to the façade [m]

# 4 Analysis of Published Data

Figure 4 plots $D_{ref}$ against $V_{ref}$ for a number of ventilators including Acoustic Louvres, Splitters Attenuators and Acoustically Lined Bends. Table 1 gives a description for each data point. Both Figure 4 and Table 1 are shown on a separate page for clarity. The data has been derived from manufacturer's published data [9,10,11,12]. Where necessary, the published data has had appropriate corrections applied to simulate the usage of the product as a façade ventilator. Data points are colour-coded to indicate whether their type - Louvres, Splitters or Lined Bend. Data points for splitter attenuators having the same free area are joined by dotted lines for clarity.

A better performance is characterised by higher values of $D_{ref}$ and lower values of $V_{ref}$ (i.e. moving towards the top-left corner of the plot in Figure 4). However the optimum compromise depends on the weighting applied to each of these values, which is likely to be project specific.

# 5 Case Studies

Five case studies (from four buildings) are presented below along with in-situ measurements of their acoustic performance.

## 5.1 Locking Castle School - Acoustic Louvres with Lined Bend

The acoustic vents have the following make-up (see Figure 5) outside-to-inside:

- 300mm deep weatherproof acoustic louvre
- 90° acoustically lined bend
- Internal insulated door – manually operated

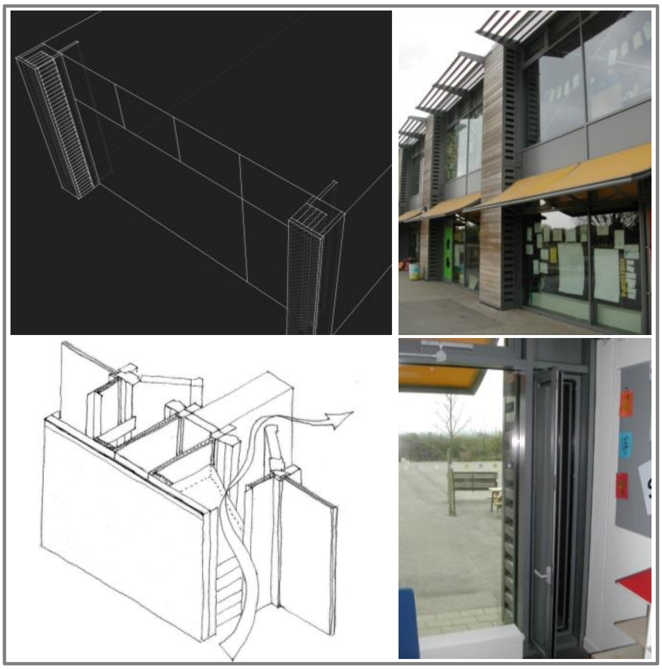

Figure 5: Acoustic louvres at Locking Castle School

## 5.2 Hackney City Academy – Acoustic Louvres with External Screen

The acoustic vents have the following make-up (see Figure 6):

- External glass screen mounted about 1m from the façade (not sealed)
- 100mm deep weatherproof acoustic louvre
- Bottom-hung window operated by a motorised chain actuator

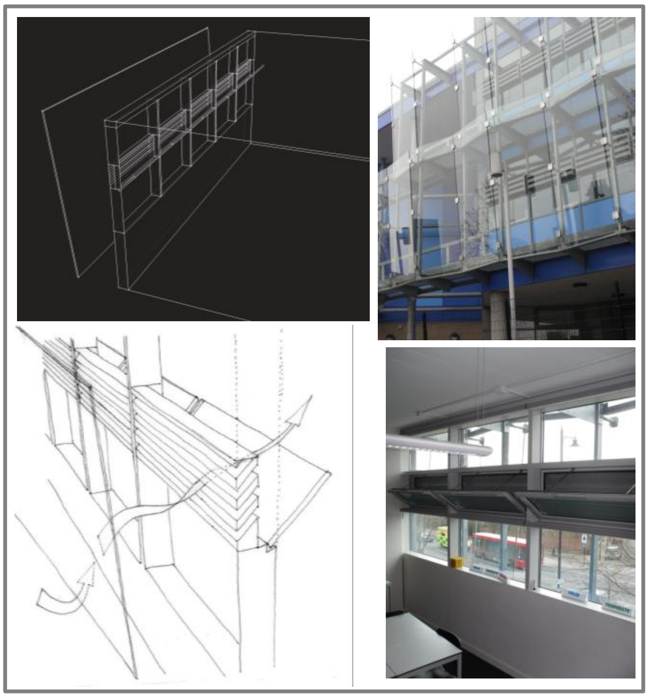

Figure 6: Acoustic louvres at the City Academy, Hackney

## 5.3 Hackney City Academy – Splitter Attenuators in Bulkhead

The acoustic vents have the following make-up (see Figure 7):

- High free-area weather louvre
- 900mm long, approximately 50% free area builders-work splitter attenuator
- Bottom-hung insulated panel operated by a motorised chain actuator

## 5.4 Cardinal Pole School – Splitter Attenuators in Bulkhead

The acoustic vents have the following make-up:

- Top-hung window operated by motorised chain actuator
- 1200mm long, approximately 60% free area builders-work splitter attenuator
- High free-area grille (not fitted at time of measurement)

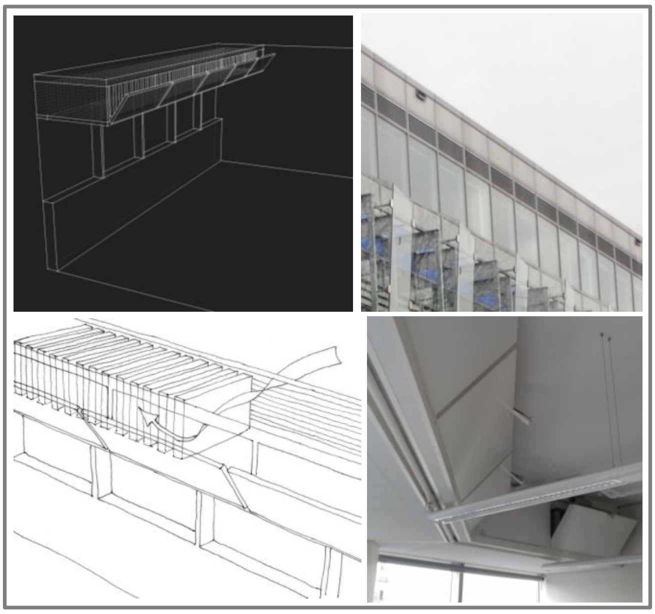

Figure 7: Splitter attenuator at the City Academy, Hackney

## 5.5 Coventry Hub – Lined Plenum with Bends

The acoustic vents have the following make-up (see Figure 8):

- Top-hung window operated by motorised chain actuator
- Builders-work, acoustically lined plenum including a 180° bend
- Bespoke perforated timber panel

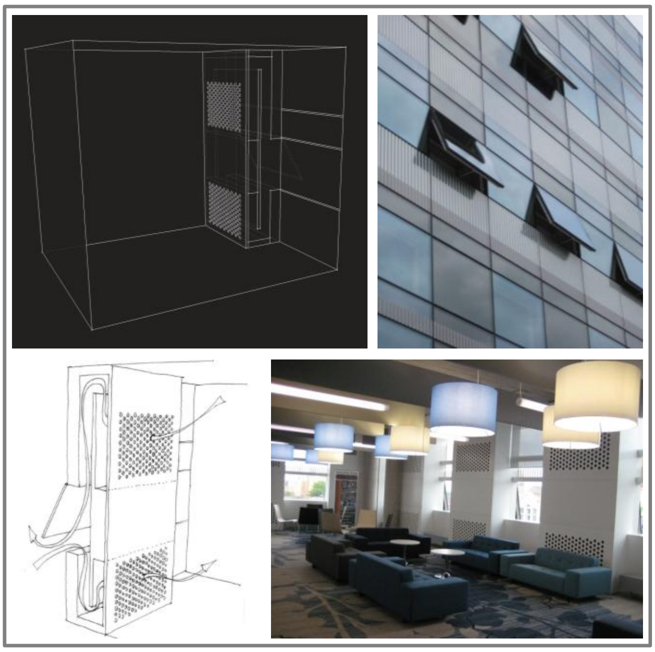

Figure 8: Lined plenum at Coventry Hub

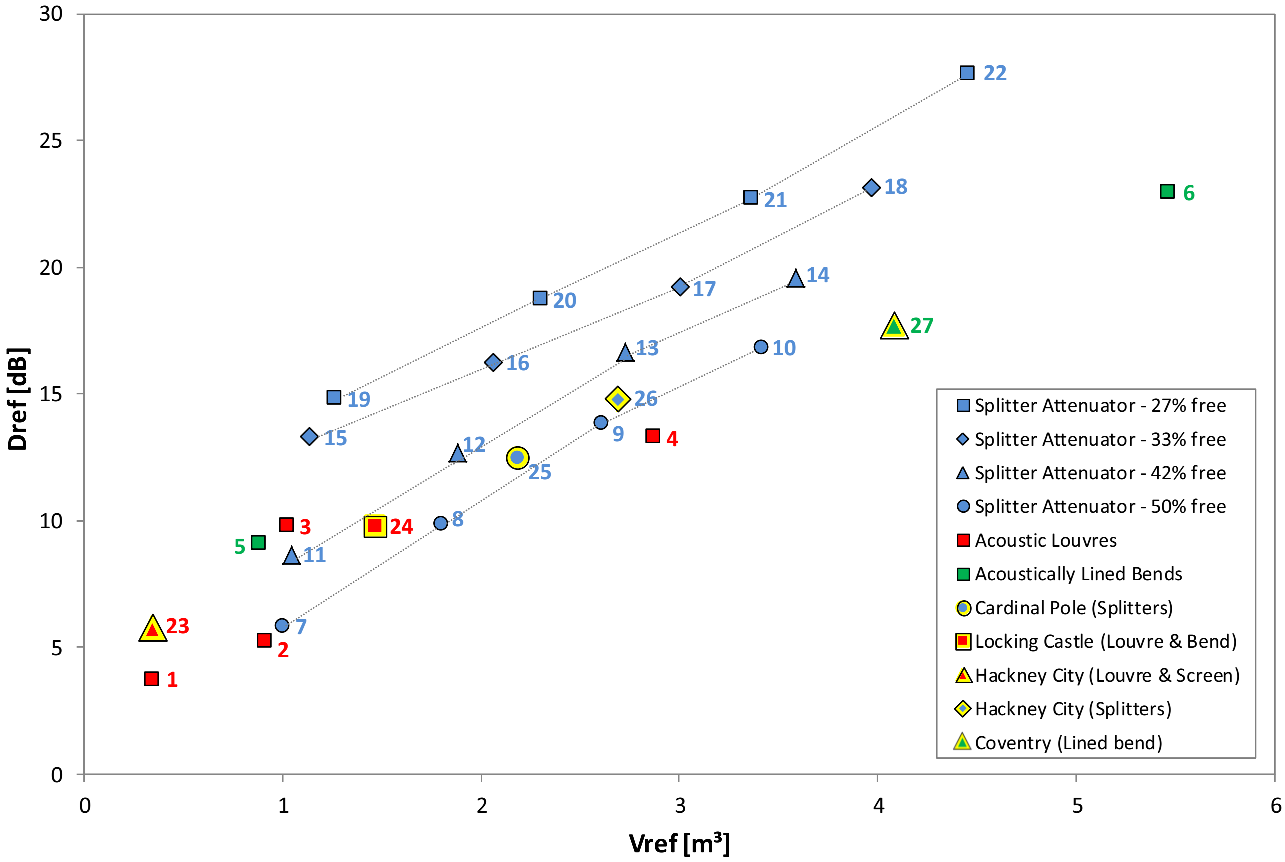


Figure 4: Plot of $D_{ref}$ vs $V_{ref}$ for 27 acoustically attenuated ventilators.

| Data point | Description | Depth |
|---|---|---|
| 1 | IAC Slimshield Louvre - SL100 | 100mm |
| 2 | IAC Slimshield Louvre - SL150 | 150mm |
| 3 | IAC Slimshield Louvre - SL300 | 300mm |
| 4 | IAC Slimshield Louvre - SL600 | 600mm |
| 5 | TEK Intonat Acoustically Lined 90° Bend with External Weather Louvre | 350mm (discounting internal dampers) |
| 6 | BRE Vent 4 - 2500mm long lined duct with 90° Bend and Grille | 2000mm |
| 7 | Trox DS-200 Attenuators (50% free area) with External Weather Louvre | 375mm (note - extrapolated acoustic data) |
| 8 | Trox DS-200 Attenuators (50% free area) with External Weather Louvre | 675mm |
| 9 | Trox DS-200 Attenuators (50% free area) with External Weather Louvre | 975mm |
| 10 | Trox DS-200 Attenuators (50% free area) with External Weather Louvre | 1275mm |
| 11 | Trox DS-150 Attenuators (42% free area) with External Weather Louvre | 375mm (note - extrapolated acoustic data) |
| 12 | Trox DS-150 Attenuators (42% free area) with External Weather Louvre | 675mm |
| 13 | Trox DS-150 Attenuators (42% free area) with External Weather Louvre | 975mm |
| 14 | Trox DS-150 Attenuators (42% free area) with External Weather Louvre | 1275mm |
| 15 | Trox DS-100 Attenuators (33% free area) with External Weather Louvre | 375mm (note - extrapolated acoustic data) |
| 16 | Trox DS-100 Attenuators (33% free area) with External Weather Louvre | 675mm |
| 17 | Trox DS-100 Attenuators (33% free area) with External Weather Louvre | 975mm |
| 18 | Trox DS-100 Attenuators (33% free area) with External Weather Louvre | 1275mm |
| 19 | Trox DS-75 Attenuators (27% free area) with External Weather Louvre | 375mm (note - extrapolated acoustic data) |
| 20 | Trox DS-75 Attenuators (27% free area) with External Weather Louvre | 675mm |
| 21 | Trox DS-75 Attenuators (27% free area) with External Weather Louvre | 975mm |
| 22 | Trox DS-75 Attenuators (27% free area) with External Weather Louvre | 1275mm |
| 23 | Hackney City Academy Louvres with External Glass Screen | 100mm |
| 24 | Locking Castle Louvre with Lined Bend | 430mm |
| 25 | Cardinal Pole Splitter Attenenuator | 1200mm |
| 26 | Hackney City Academy Splitter Attenuator | 1000mm |
| 27 | Coventry Hub Lined Plenum with Bends | 1870mm (oriented in vertical) |

Table 1: Description of acoustically attenuated ventilators shown in Figure 4.

## 5.6 Measured Acoustic Performance and Analysis

The in-situ acoustic performance values for the five case studies above are shown in Table 2. The calculated equivalent area for each ventilator is also shown (refer to Equation 4). The five case studies are also shown on the plot of $D_{ref}$ vs $V_{ref}$, (see Figure 4). The data points are colour-coded with the yellow border indicating that they are in-situ measurements and the centre colour indicating the base ventilator type - Louvres, Splitters or Lined Bend.

The $D_{n,e}$ value for the vent is estimated from the in-situ $D_{tr,2m,nT}$ or $D_{ls,2m,nT}$ value using the following relationship:

$$D_{n,e} = 10.log_{10}\left(\frac{0.5}{V}\right)$$
$$-10.log_{10}\left[10^{\left(\frac{-D_{nT,open}}{10}\right)} + \left(\frac{A_{face}}{A_{facade}} - 1\right).10^{\left(\frac{-D_{nT,closed}}{10}\right)}\right]$$
$$+ G + 18dB \qquad (8)$$

Where:

- V = volume of the test room [m³]
- $D_{nT,open/closed}$ is the measured $D_{tr,2m,nT}$ or $D_{ls,2m,nT}$ with the acoustic vents open/closed
- $A_{facade}$ = total area of the test room façade [m²]
- G = Geometric factor =1 for point source at normal incidence, =3.6 for line source at normal incidence

This ignores any difference between in-situ and laboratory values due to flanking etc. It also inherently assumes that the closed vent gives a sound reduction equal to the composite value for the sealed façade.

| Project | Dtr,2m,nT,w (+Ctr) | Aequivalent |
|---|---|---|
| Hackney City Louvre | 23(-2)dB | 1.2 m² |
| Hackney City Splitters | 29(-3)dB | 2.6 m² |
| Coventry | 28(-3)dB | 0.8 m² |
| **Project** | **Dls,2m,nT,w (+Ctr)** | **Aequivalent** |
| Locking Castle | 28(-3)dB | 1.0 m² |
| Cardinal Pole | 30(-6)dB | 2.4 m² |
| *Note 1: In accordance with BS EN ISO 140-5: 1998, BS EN ISO 717-1:1997* | | |
| *Note 2: Aequivalent predicted using CIBSE C method* ***[5,7,13]*** | | |

Table 2: In-situ measurements of acoustic performance

# 6 Conclusions

The $D_{ref}$ value gives a measure of the level difference (outside to inside) that can be achieved, relative to a simple window opening giving the same amount of ventilation. All of the attenuated ventilator designs considered show an increased acoustic performance relative to a window.

The choice of ventilator design will be driven by the specific requirements of the project - in particular what level of attenuation is needed and how much space is available for the ventilator.

Acoustic louvres are a good option when modest levels of acoustic attenuation are required (up to around $D_{ref}$=10dB). This is because no additional space is needed for a weather louvre.

Splitter attenuators are the most space efficient option (in terms of $D_{ref}/V_{ref}$) when higher levels of acoustic attenuation are needed ($D_{ref}$>10dB). This is because, the space required for a weather louvre is a less significant part of the overall space requirement. Splitter attenuators also have a better ratio of acoustic attenuation to pressure loss. This is because the splitters are aligned with the air-stream and are absorbent on both sides. Splitter attenuators probably also give a larger end-reflection effect. It is more space efficient to use a shorter, lower free-area splitter attenuator than a longer, higher free-area one.

Lined bends and plena are a good option when modest levels of acoustic attenuation are required (up to around $D_{ref}$=10dB) but are not a space efficient solution (in terms of $D_{ref}/V_{ref}$) for higher attenuation situations. However, they have the advantage of being simple and inexpensive to build.

A marked uncertainty in this study is the prediction of the pressure loss associated with the ventilators. These have been calculated from reference data and there are likely to be significant errors associated with combining pressure losses from components in series and from extrapolating values down to the very low flow velocities that are typical in natural ventilation. Going forward, it would be preferable to be able to measure pressure loss values directly under representative flow conditions.

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