SOUNDSCOOP: DEVELOPMENT AND APPLICATION OF AN ACOUSTICALLY OPTIMISED LOW RESISTANCE VENTILATOR

S Colam FISH Innovation Ltd

1 INTRODUCTION

SoundScoop^{TM} is a commercially available ventilator designed for applications where targeted attenuation of noise and low resistance air flow are a priority. It is particularly suited to buildings which employ a natural (i.e. non-mechanical) ventilation strategy. The basic design concepts were based on the author's doctoral research and subsequently developed as part of a 'new product' initiative while employed at Arup. The resulting proof of concept led to a partnership between Arup and Passivent, enabling the product to be brought to market.

SoundScoop^{TM} was initially conceived as a cross-ventilation unit and has been successfully installed in numerous buildings. Given that the majority of occupational noise in buildings is associated with footfall and speech, the attenuation is predominantly at mid-frequencies. In response to industry feedback, a façade unit has been developed in recent months designed to exhibit broadband attenuation appropriate for controlling external urban noise ingress.

This paper concentrates on the technical development of these products. The target acoustic specifications will be discussed, from which point the design approach is described. UKAS accredited test results will be presented as evidence of the acoustic performance. Whilst reference will be given to the air flow characteristics, it will not be described in detail.

2 CROSS-VENTILATION UNIT

2.1 Contextual Acoustic Specification

The design of the cross-ventilation SoundScoop (herein referred to as XSS) started by establishing the acoustic specification in the context of its use. The dual requirement of sound attenuation and low resistance airflow is somewhat mutually exclusive and so it was critical to precisely define the frequency range which the XSS would target. Providing effective broadband attenuation from a short 'letterbox' style design would not have been feasible.

Analysis of occupational noise in buildings identified people movement and speech to be the dominant sources. For a cross-ventilation path, it is this noise that must be controlled and therefore the XSS specification centered on attenuating sound in the 500Hz – 2kHz frequency range. This limited bandwidth of attenuation meant that achieving the necessarily open design for the airflow was more achievable.

2.2 Shape, Size and Position

Having established the outline acoustic specification the basic design principles were developed, some of which were determined by its use as a cross ventilation path.

Given that cool air displaces more buoyant warm air, cross-ventilation paths are typically placed at high level. This position is normally outside of the plane of noise source and receiver and thus there is not 'line of sight' through even a very open path. Based on this, it was considered unnecessary to include a bend or splitters, enabling the XSS to take the form of an unobstructed slot. Figure 1 illustrates a typical installation.

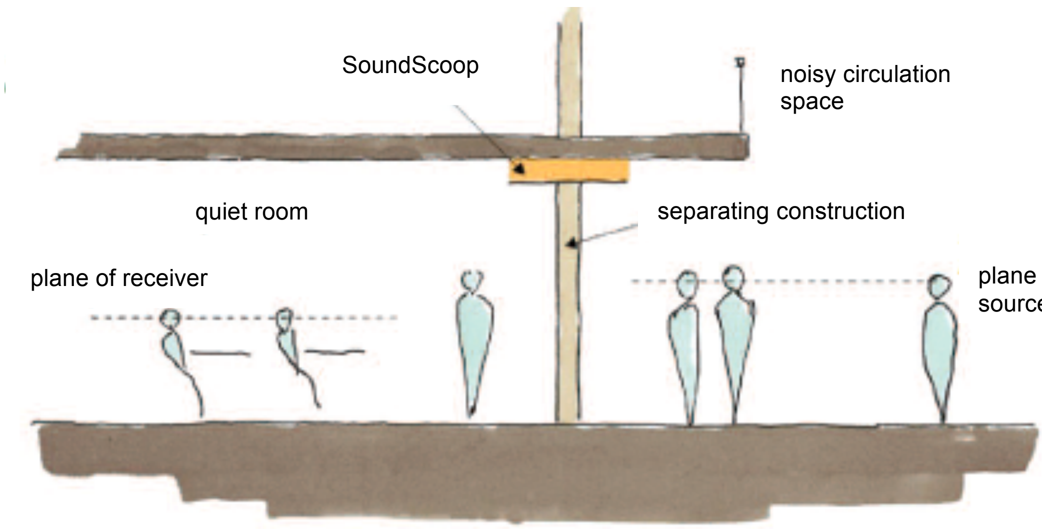

Figure 1 Typical application of the XSS in a naturally ventilated building

The cross sectional dimensions were determined based on the requirement for mid frequency attenuation. After considerable modeling, 600 x 300mm was shown to be most effective as this resulted in 'double modes' in the 500 – 2kHz frequency range. The XSS length was always considered an important aspect and the design intent was for it to be limited to 600mm in the majority of situations.

2.3 Ribbed Internal Lining

The main inventive step in the XSS design related to its internal lining. Research by the author had identified the benefit of a impedance discontinuities and it was considered worthy of further consideration. The primary mechanism was thought to be ½ wavelength cancellation associated with the period of lining discontinuity, as well as scattering of the plane wave into higher order modes that are more readily absorbed by a porous material.

Extensive modeling and testing showed the reactive ½ wavelength attenuation to be negligible and while some scattering was evident, a discontinuous lining achieved by interrupting the porous material with solid ribs resulted in a different effect. The peak in attenuation was closely associated with modes operating across the cross section of the unit. The 'segmentation' of the porous lining seemed to emphasize these transverse modes and limit the 'group speed' of the mode as the frequency increased[1]. In other words, the protruding ribs encouraged the modal wavefronts to be normal to the length axis of the XSS unit, resulting in a more resonant attenuation characteristic.

The final lining design featured 50mm deep ribs at 100mm centres with 50mm thick 100kg/m^3 mineral wool placed in between. Comparison with continuous porous linings showed that a 10dB increase in attenuation could be achieved at frequencies associated with the first few cut-on modes.

2.4 Measured Attenuation

Figure 2 shows the accredited test results (in $^1/_3$ octave bands) for a 600mm and 900mm long XSS unit. Both units exhibit a free area of $0.1m^2$ and an airflow resistance of Cd 0.7.

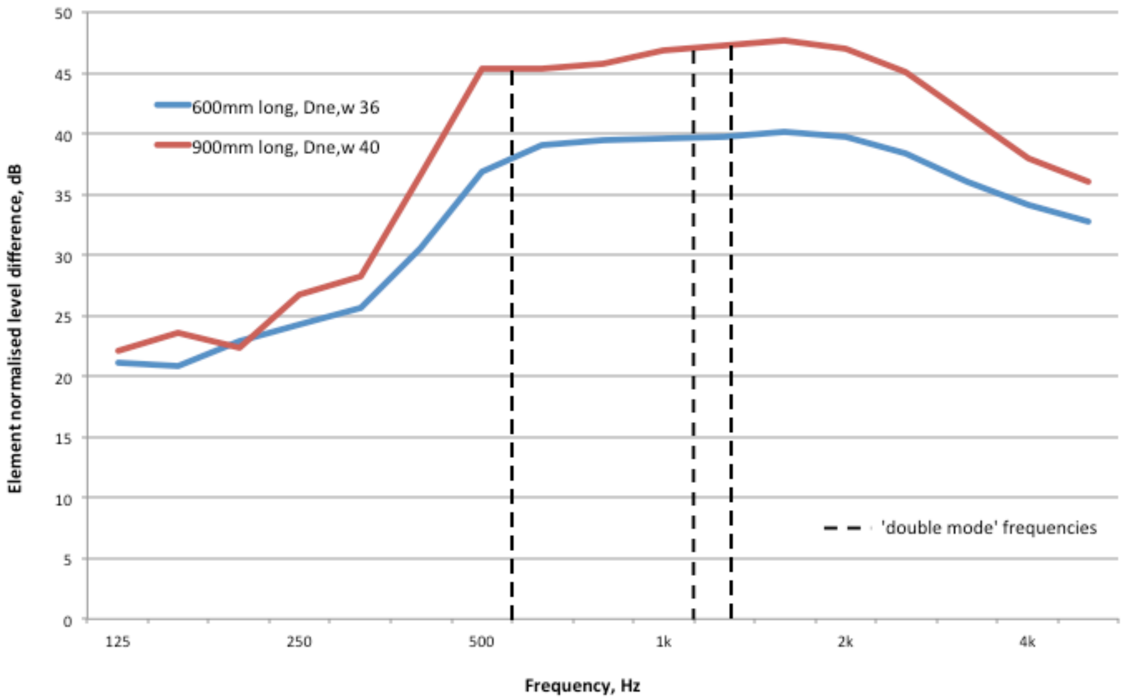

Figure 2 Accredited test results for a 600mm and 900mm long XSS

With reference to the latest acoustic performance standards for schools[2] the XSS is an ideal product for classroom cross-ventilation. In smaller spaces, two 600mm XSS units can be used for standard classrooms or two 900mm XSS units for music rooms and the like. In large standard classrooms, up to seven 900mm XSS units can be used to achieve the requirement of $D_{ne,w}$ = 32 + 10log(N).

3 FAÇADE VENTILATION UNIT

3.1 Urban Noise Levels – Spectra and Distribution

As with the XSS, it was necessary to establish a specification for the Façade SoundScoop (FSS) based on external noise and standard targets for internal levels in buildings. A large sample of attended noise surveys undertaken by Arup Acoustics were used to determine typical urban noise spectra during the day and night. These results were also used to look at the level distribution of ‘A’ weighted values.

Figure 3 shows the average daytime and night time spectra derived from these surveys. The contribution from traffic is seen at low frequencies. Figure 4 shows the distribution of the ‘A’ weighted measurements from all the surveys. A peak in the histogram is evident in the 55-65dB(A) range during the day and 45-55dB(A) at night. These values account for 62% and 48% of the total sample population, respectively. The solid and dashed outlines identify those noise levels which are too high to open windows. Detailed discussion on the *passive vent that offers 10dB(A) more sound reduction than an open window* is given later in this section.

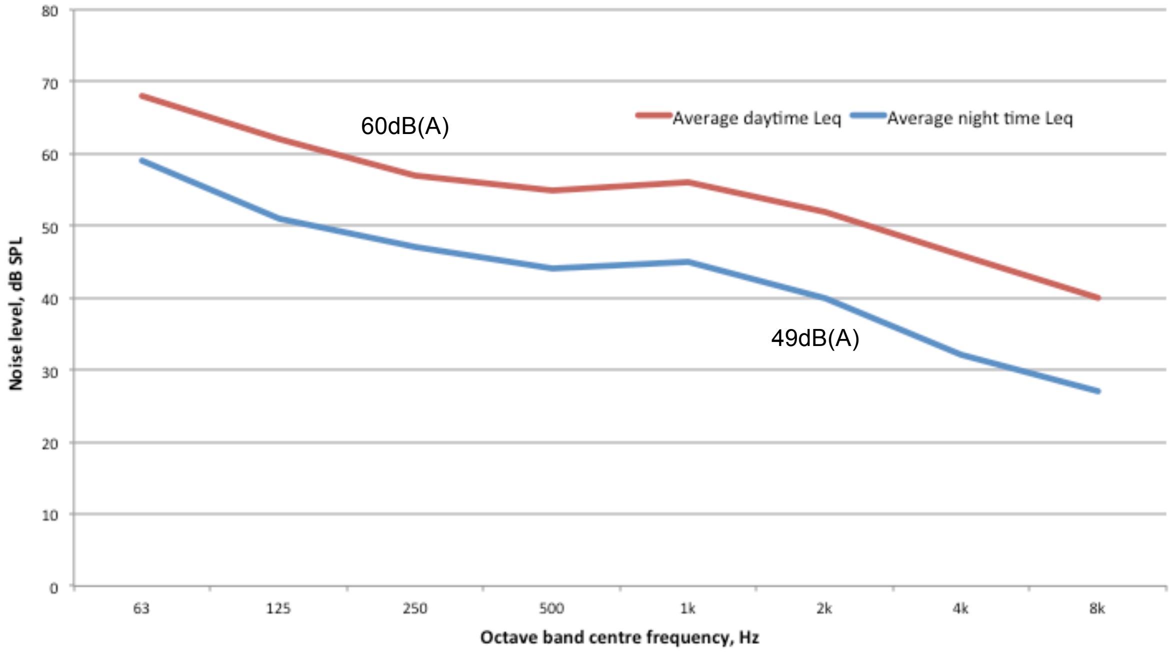

Figure 3 Average daytime and night time urban noise spectra

For the purpose of comparison, the modeling results from Noise Mapping England[3] were used to estimate the distribution of noise levels in urban agglomerations. This analysis suggested that during the day 81% of the population are exposed to noise in the 55-65dB(A) range, with exposure to 45-55dB(A) accounting for 55% of the population at night.

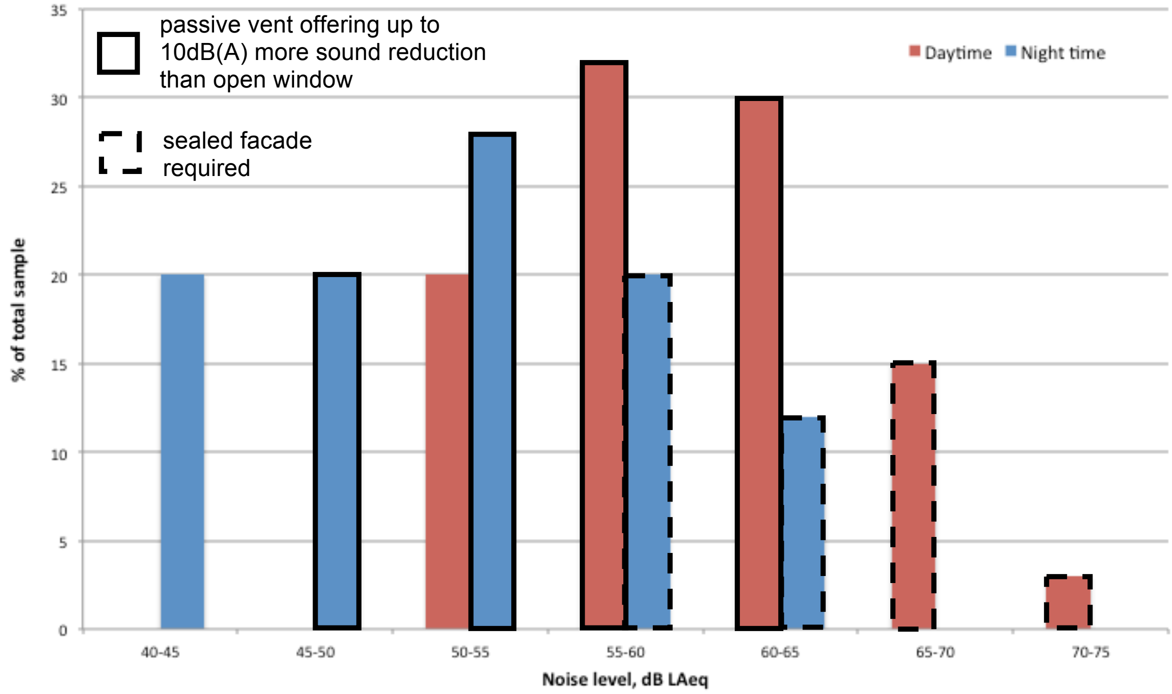

Figure 4 Distribution of 'A' weighted urban noise levels

The significance of the 55-65dB(A) daytime and 45-55dB(A) night time levels becomes clear when we consider that the composite level difference of a façade with an open window is about 15dB(A). The statistical analysis above shows that the majority of urban noise occurs in a range that is too high to allow ventilation of an office, classroom or bedroom simply by opening a window. The noise ingress would be up to 10dB(A) too loud for both a daytime working environment (maximum of 40dB(A)[2]) and an room conducive to restful sleep (maximum of 30dB(A)[4]).

Combining the spectral noise data and the population exposure to median noise levels, allowed an acoustic specification for the FSS to be established: *a low airflow resistance ventilator exhibiting a nominally frequency independent attenuation of around 10dB.* Achieving this target would enable the majority of the urban population to naturally ventilate their workplace and home. The bold solid outlines in Figure 4 illustrate this point by highlighting the proportion of urban noise which could be satisfactorily attenuated by the aforementioned ventilator. Given the practical constraints on the length of façade ventilators, the challenge with this specification would be in achieving the necessary low frequency performance.

3.2 Size and Shape

The understanding gained from developing the XSS meant that the optimum dimensions of the FSS could be quickly determined. In order to achieve broadband attenuation the cross sectional dimensions were chosen to provide an even distribution of modes with frequency – the outer shell measures 800 x 250mm. Unlike the XSS, the façade unit would not have standard options for different lengths, so it was important to keep it as short as possible – 400mm was chosen. The details of the air path would be determined by the lining design, an aspect of the development which involved numerous iterations.

3.3 Asymmetric Lining and Helmholtz Resonance

The requirement for broadband attenuation meant that a thick lining would be required to damp the low frequency modes, which would in turn limit the free area required for the low resistance airflow. However, unlike the XSS, only modest attenuation was required and this led to a design that used different thickness of lining on each on the four internal surfaces. A ‘primary’ lining was designed to damp the modes operating across the width and height of the unit, with a 25mm thick ‘secondary’ lining included to limit any ‘short-circuiting’. Figure 5 shows this design.

The ‘primary’ linings were 50mm thick for the short dimension and 200mm thick across the width of the unit. The former had been shown to work well for the XSS for frequencies above 500Hz. Partly due to manufacturing considerations, the 200mm lining was developed to include a Helmholtz resonator. The dimensions of the FSS provided a cavity volume that enabled the resonator to be tuned to 150-250Hz depending on the dimensions of the aperture. Figure 6 shows a photograph of a prototype design being tested.

As before, a rib spacing of 100mm was chosen with the thickness of 100kg/m^3 mineral wool matching that of the adjacent ribs. Like the XSS, this design provided a free area of 0.1m^2 and given the same ‘letterbox’ geometry, provided a similarly low pressure drop.

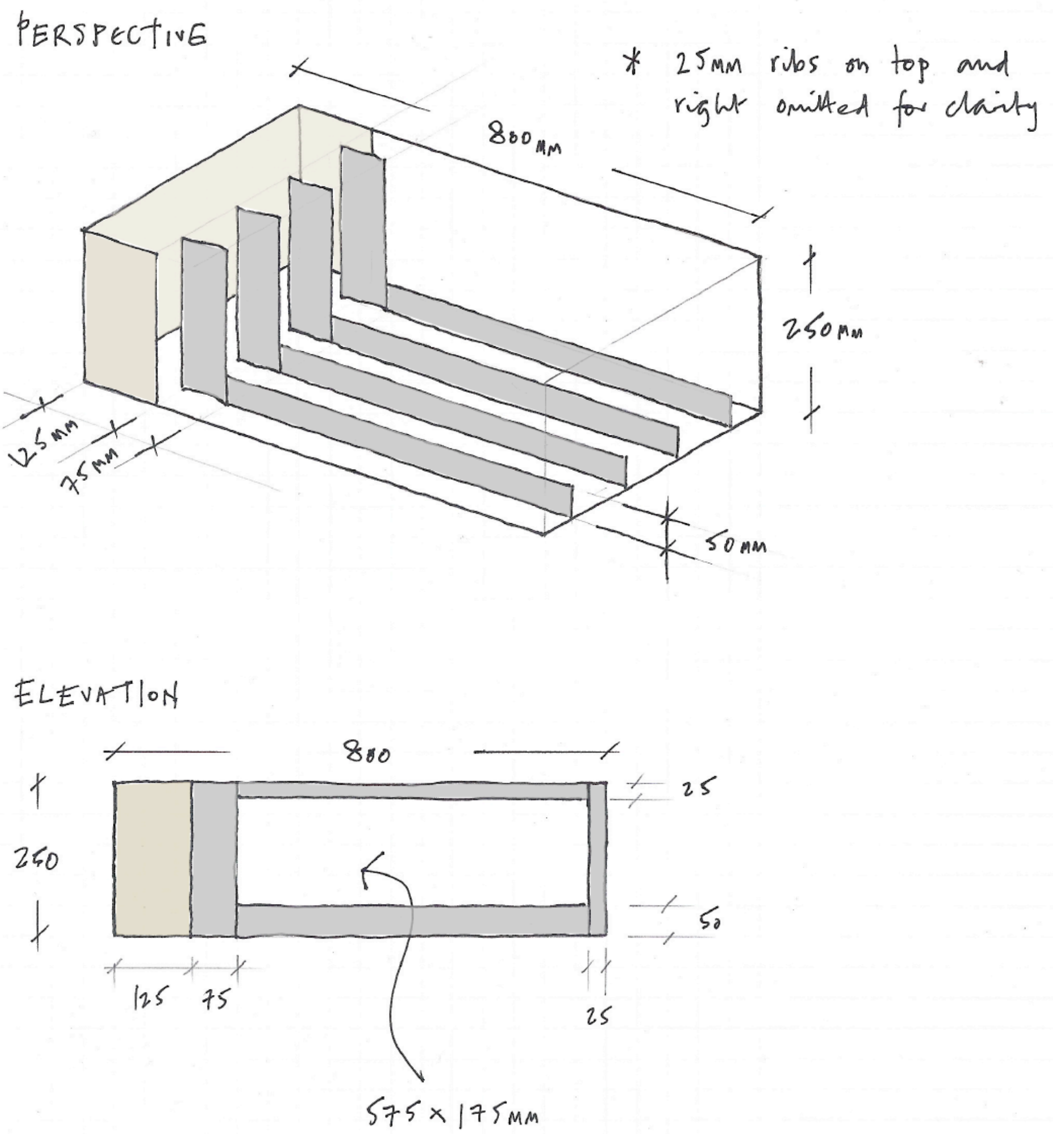

Figure 5 Sketch design of the FSS showing the primary and secondary linings

3.4 Measured Attenuation

The design was developed through tests at Passivent's manufacturing facility near Nottingham, however due to measurement uncertainty at low frequencies, the final choice of cavity perforations were made through the accredited testing at AIRO.

Numerous configurations were tested and it was determined that two 25mm diameter perforations between each rib provided the best low frequency attenuation. The predicted Helmholtz resonance for a given perforation size was evident in the test results with peaks in attenuation at 160, 200 and 250Hz.

Figure 6 shows the results for the standard 400mm long unit and a shorter 300mm unit. The weighted element normalized level difference is given along with the traffic noise spectrum adaptation term.

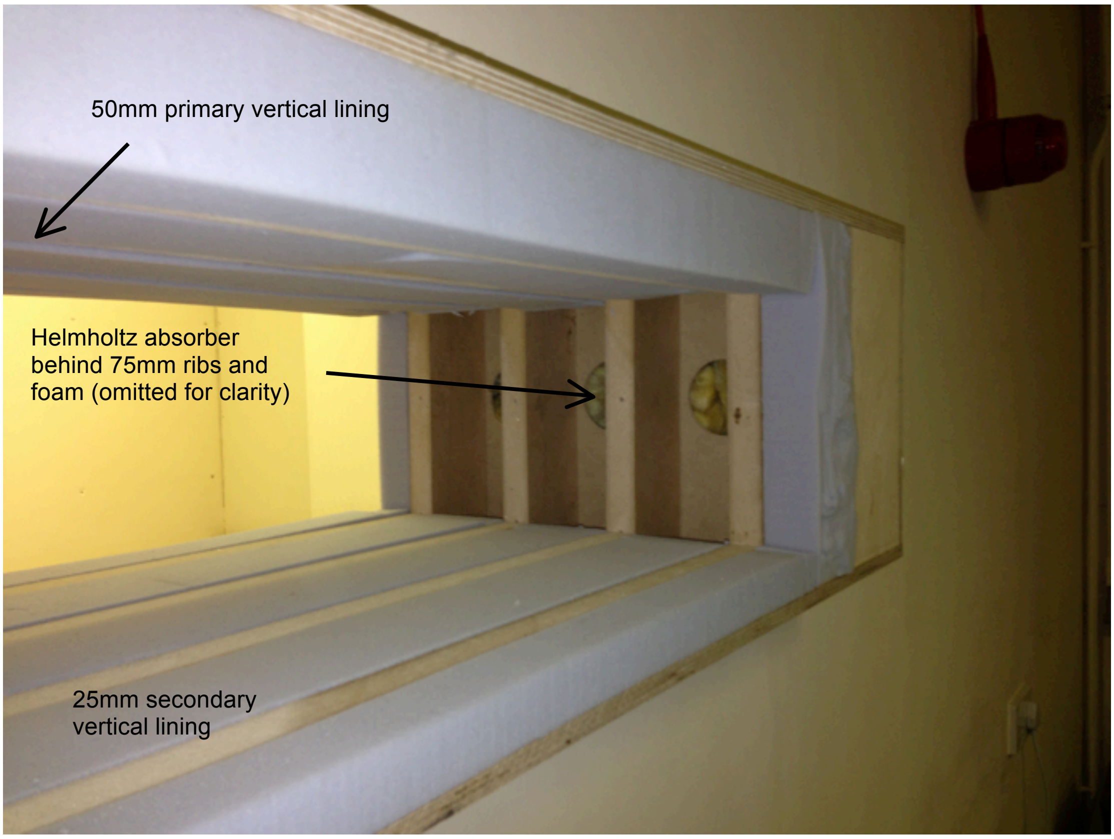

Figure 6 Photograph of the prototype FSS being tested

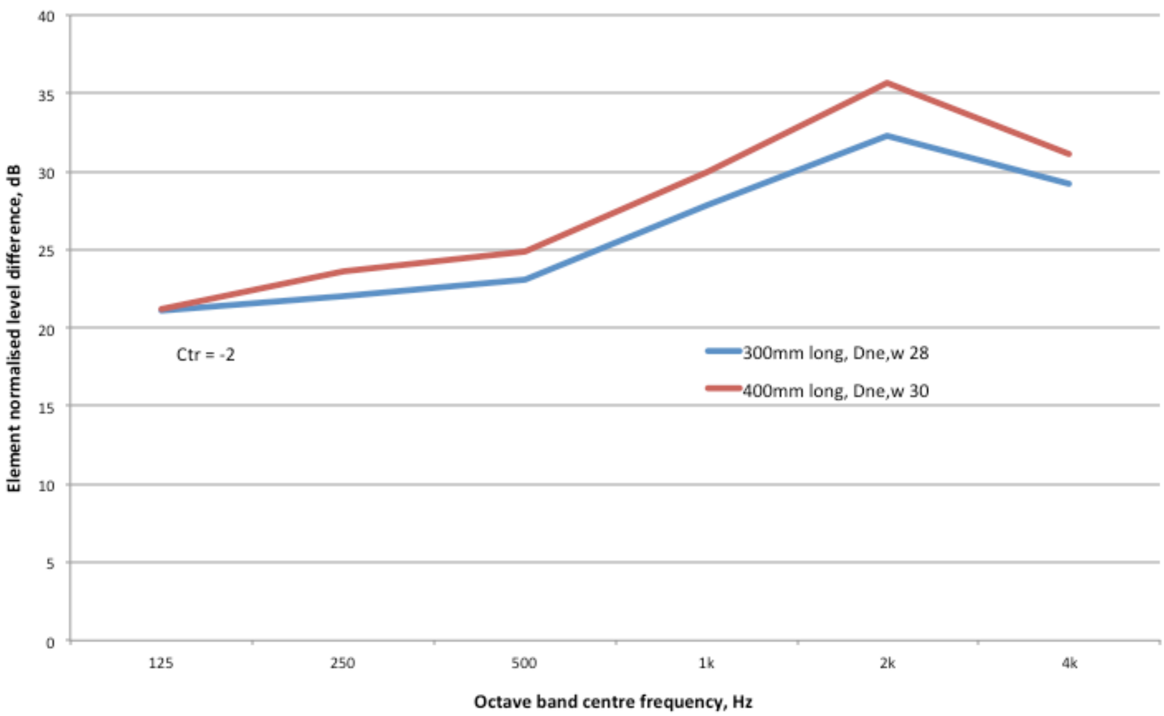

Figure 7 Accredited results for the Façade SoundScoop

The results for the FSS show that significant attenuation, even at low frequencies, is achieved. Figure 7 indicates how this performance translates to the internal noise levels of a building, based on the composite transmission loss of the façade. This result assumes a total façade area of 18m^2 with 6m^2 of glazing and a free ventilation area of 0.4m^2. Given that the FSS has a 50% open area, the units occupy 0.8m^2 of the façade. Assuming a roadside noise level of 65dB(A) the FSS would allow a school to be built 40m from the road. Ventilation via opening windows would require the façade to be 115m from the road in order to achieve the same internal level of 35dB(A).

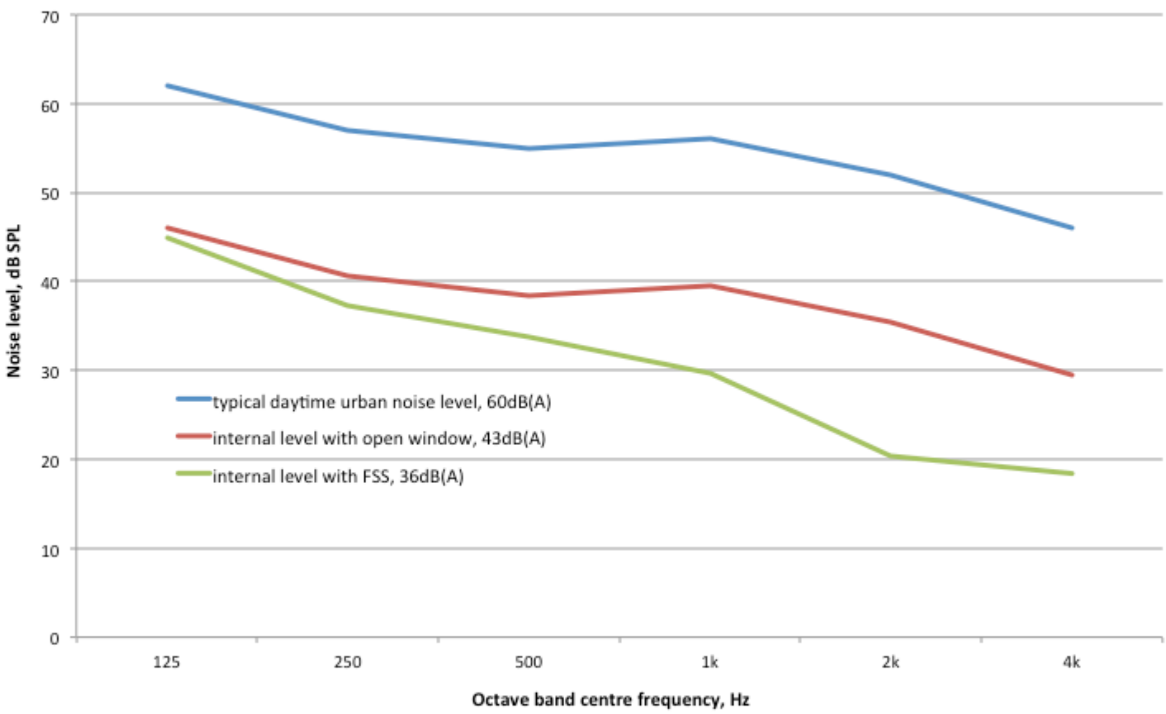

Figure 8 Predicted internal noise levels for a 400mm FSS and an open window of equal free area

4 CONCLUSIONS

The two ventilators described exhibit significant attenuation of sound in the frequency range for which they were designed. In both cases, the ribbed lining has been show to emphasize modal activity which enables the performance to be even more targeted. The attenuation is remarkable given the 'letterbox' design and negligible air resistance.

The FSS has built on these design principles by employing a resonant cavity. Whilst this has provided an increase in low frequency attenuation, work will continue towards achieving a 10dB(A) improvement on an open window of equal free area.

5 REFERENCES

1. L. Kinsler and A. Frey. Fundamentals of Acoustics, 3rd edition, John Wiley & Sons, 216-219. (1982).
2. Education Funding Agency. Acoustic Performance Standards for the Priority Schools Building Programme. (2012)
3. Environmental Noise (England) Regulations 2006.
4. World Health Organisation. Night Noise Guidelines for Europe, 108-110. (2009)