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NOISE CONTROL TECHNIQUES FOR NATURALLY VENTILATED BUILDINGS

Steve Sharples*, Max de Salis+ and David Oldham+

*** Centre for the Built Environment, School of Environment and Development, Sheffield Hallam University, Sheffield S1 1WB, UK**

+ Acoustics Research Unit, School of Architecture and Building Engineering, University of Liverpool, P.O. Box 147, Liverpool L69 3BX, UK

SYNOPSIS

There has been a growing interest in the use of natural ventilation in buildings to supplement or replace mechanical air supply systems. However, for buildings in busy urban areas the potential to use natural ventilation can be limited by excessive noise entering through natural ventilation openings such as windows and trickle ventilators. Such openings tend to have large open areas to enhance air flow while offering a very low resistance to the transmission of external urban noise. Traditional treatments for controlling the ingress of noise through an opening tend to increase significantly the air flow resistance of the opening, thereby making natural ventilation non-viable. This paper describes some experimental studies of alternative forms of noise control that do not create an increased resistance to air flow. The first alternative was a passive system consisting of a panel containing sound absorbtent material fixed in front of a ventilation opening. The second alternative investigated was an active noise control system which attempted to sample the urban noise spectra close to the inlet opening and neutralise the noise by injecting the inverse spectra ('anti-noise') in to the air supply. Finally, a hybrid system incorporating both the passive and active techniques was tested. Initial results suggest that this hybrid approach may yield a design strategy that allows urban buildings to benefit from natural ventilation whilst maintaining an acceptable internal acoustic environment.

I INTRODUCTION

If a natural ventilation approach is to become more common in noisy urban areas then more information needs to be provided to designers about different approaches to noise control. It may be argued that a common design approach when deciding on ventilation strategy is to gauge if the external environment is noisy, and if it is to take the easiest option i.e. that of mechanical ventilation. In mildly noisy environments acoustic louvres are most often used as inlet or outlet devices in cases where natural ventilation is applied. In more innovative cases splitter attenuators have been used in very noisy environments where the incumbent large aerodynamic pressure loss is overcome by using tall stack chimneys rising high above the building to overcome pressure loss [1]. For domestic buildings in noisy environments acoustically treated trickle ventilators provide low levels of background ventilation which is supplemented by rapid ventilation when required.

The most common acoustically treated device used in larger non-domestic buildings with natural ventilation strategies is the acoustic louvre. Originally, louvres were designed to give weather protection while allowing airflow. Acoustic louvres, which may be described as ordinary louvres with sound absorbent material applied under the blades, grew out of these and were originally aimed at suppressing internal noise break-out from building services plant to the exterior. However, when attenuation is required from an exterior source then, despite the lower initial sound pressure level of the source compared to an internal plant room, the attenuation requirements will often be higher than for break-out noise due to the fact that (i) the external free-field noise will pass directly into the enclosed room with the treated aperture as the only attenuation mechanism and (ii) 6 dB will be added to the attenuated free-field noise level as it is transferred to an interior reverberant field [2].

Another possible approach to natural ventilation is the use of some sort of screened aperture such as those described and analysed later in this paper. However, standard test methods to assess the performance of this type of ventilator to free field noise sources are difficult to implement. Therefore test methods need to be identified which will give assessments of performance of various ventilators before attenuation information can be processed. The acoustic performance of a ventilator needs to be presented in conjunction with airflow performance data so that the designer can select an approach that will satisfy attenuation and will fit in with other design requirements. Then the designer may go about designing a system to achieve the required pressure differentials to achieve the design flow rates. Results presented in this report using non-standard methods to test screened apertures suggest that to achieve a workable system in terms of aerodynamic and sound insulation performance may be more of a possibility than perhaps was thought previously. However, it may mean looking past the acoustic louvre as a means of attenuation and looking towards designing innovative flow systems.

A more speculative method to achieve sound insulation would be the application of active noise control in the inlet ducts to the system. This theoretically should add no airflow load to the system and works at low frequencies where traditional elements such as louvres will have limited effectiveness. This is highly applicable as large amounts of low frequency noise will be generated in areas of slow moving traffic such as urban areas, especially in cases where traffic is accelerating from junctions. To achieve good low frequency sound insulation with a louvre type mechanism would require large amounts of dissipative material which would also incur untenably large flow resistances. Therefore, an effective active noise control approach would be beneficial in these areas. Results of active attenuation of recorded traffic noise in ducts are shown and the technique proves to be highly effective for attenuating low frequency traffic noise under laboratory conditions.

II ACOUSTIC TEST PROCEDURES

A. Acoustic testing of passive elements

Most standard acoustic tests for transmission characteristics of building façade elements [3] use reverberant fields as the source room fields. For solid panel tests the results from these standard reverberant room tests are easily transferrable for use with a free field source such as road traffic noise. However, reverberant source field measurements of façade ventilators will not necessarily be transferrable in this way due to the highly directional relationship which can occur between the incidence of the source field and the direct fluid path through the element. Thus while a particular ventilator's attenuation performance may be considerable for an approximately 2-dimensional directional free field such as traffic noise it may collapse under 3-dimensional diffuse source field conditions. Tests do exist for the evaluation of the acoustic performance of façade elements and facades to free field sources of this nature but these are normally only carried out post-construction and in-situ [2]. It may be argued that this type of test should be applied to façade ventilation mechanisms for free field sources such as road traffic noise, thus giving an indication of variation in performance with angle of view performance with angle of source as set out using a loudspeaker approximation [3].

Using a filtered source with a high-pass cut-off frequency of 250 Hz in the anechoic chamber at the University of Liverpool provided the equivalent of free-field conditions. A partial baffle with an aperture for mounting of test specimens has been built with a view to undertaking a scale model version of the façade element test detailed in ISO 140 part 5 using the intensity method. The test set-up achieves measurement conditions which comply to the measurement of transmission loss of panels using intensimetry as detailed in BS ISO 15186-1:2000 [4] with two exceptions:

1. the source field condition which in this case is free-field rather than reverberant. This is valid when applying intensimetry [2].

2. the quantity measured is insertion loss using an amplified white noise source rather than direct room to room transmission loss. This is a perfectly valid approach under free-field conditions with a repeatable noise source such as this.

The passive acoustic / airflow element tested in the anechoic chamber consisted of a 350 by 350 mm absorption backed plate screening a 50 by 50 mm aperture in a test baffle as shown in Fig. 1.

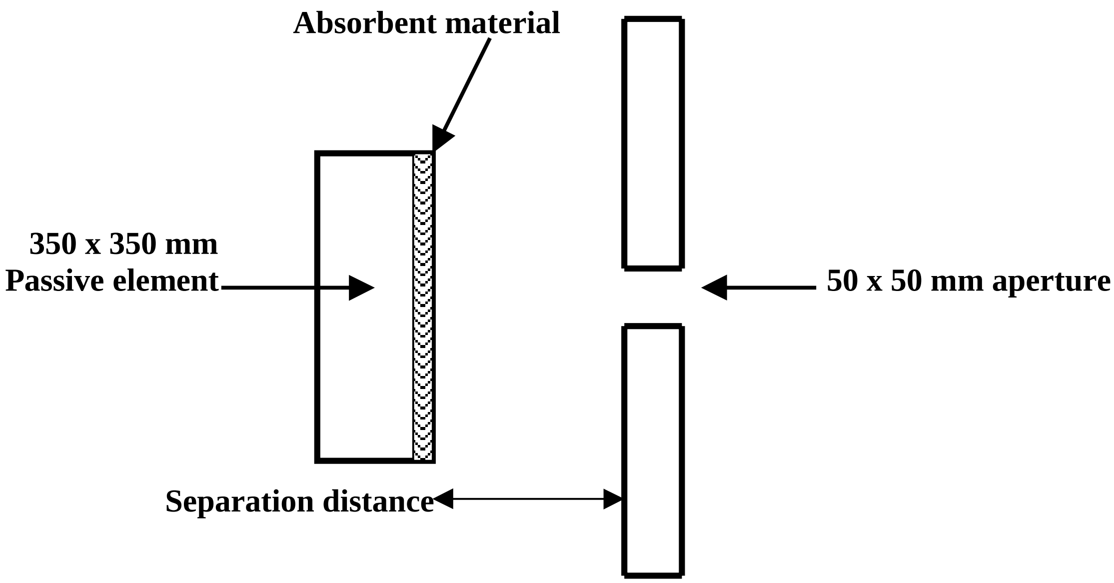

Fig. 1 Schematic of passive panel / aperture testing for free field to free field insertion loss.

B. Acoustic test results for passive elements

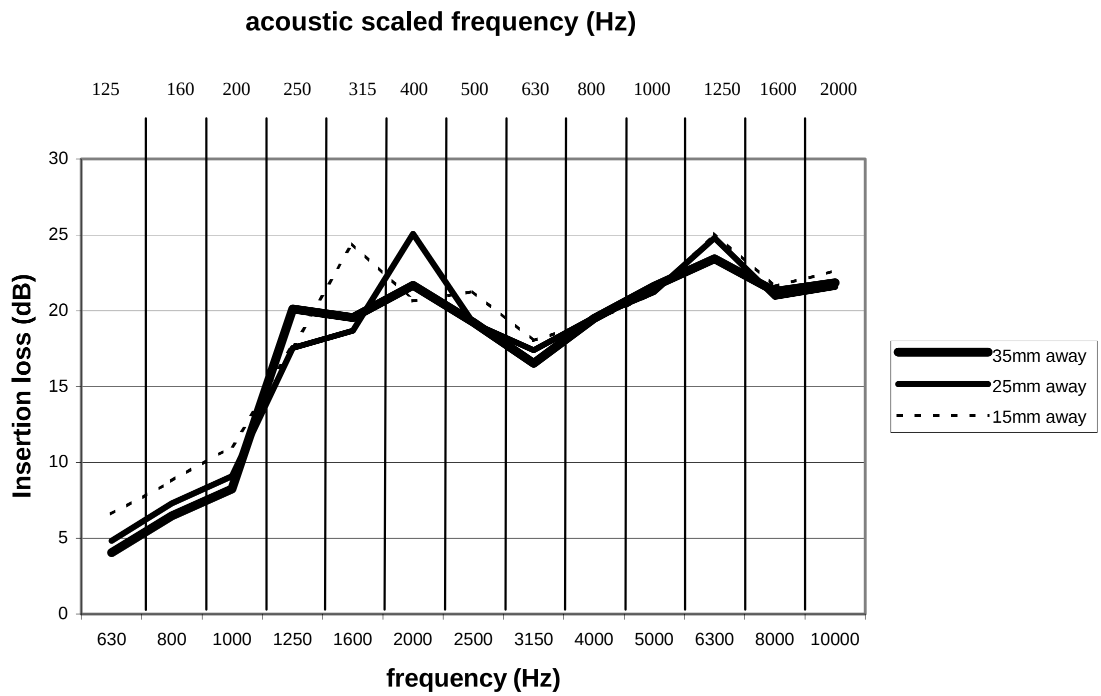

Fig. 2 Free field to free field insertion loss for 350 by 350 mm screen placed at various distances normal to a 50 by 50 mm aperture in a partial baffle.

Measured insertion loss results for normally incident sound from 630 Hz to 10000 Hz for a 350 by 350 mm absorption backed plate screening a 50 by 50 mm aperture in a test baffle are shown in Fig. 2. The insertion loss was measured with the screen at varying distances normal to the aperture to gauge any variation in insertion loss with distance. It is noted that at low frequencies in the range some benefit is gained by moving the plate closer. However, in the higher frequency range little variation is noted with distance from aperture.

Insertion loss results for larger ventilators may be predicted by scaling the frequencies down by the scaling ratio of the larger element to the test element. Using this method and assuming the previous measurements were taken on a 1:5 scale model then the results from 630 Hz to 10000 Hz may be transposed to full scale in the range 125 to 2000 Hz which is often taken as the frequency range of interest for traffic noise [7]. The scaled frequency range is shown in Fig. 2.

III. AIRFLOW TEST PROCEDURES

A. Airflow testing of passive elements

Airflow tests were carried out using a purpose built test rig consisting of a plenum chamber of approximately 1 m^3, a fan and a precision laminar flow metering device devised for the measurement of air flow through and pressure differential across the test component. Measurements of pressure differential were taken for various flow rates induced by the fan and the previously determined leakage of the box was subtracted to obtain the pressure to flow rate characteristic of the measured ventilator devices.

B. Airflow test results for passive elements

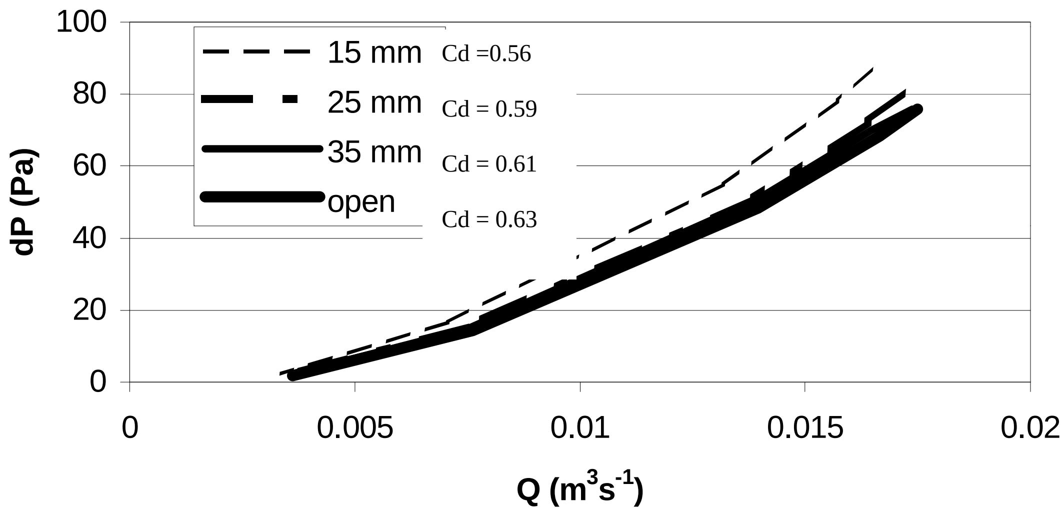

Fig. 3 Pressure differential versus flow rate for 350 by 350 mm screen placed at various distances normal to a 50 by 50 mm aperture in a partial baffle.

Measured pressure to flow rate characteristics for the 350 by 350 mm absorption backed plate screening a 50 by 50 mm aperture at various distances normal to the aperture are shown in Fig. 3. The increase in pressure differential for an required flow rate is small as the plate is moved closer to the hole reducing the airflow path and this is reflected in the small variation in flow coefficient Cd [8]. The curve of the lowest pressure differentials is that of the open hole showing minimal increase in pressure loss over the open hole condition which has a measured flow coefficient close to the expected flow coefficient of a thin orifice plate of 0.61 often used for large openings [8].

IV. COMBINED AIRFLOW AND ACOUSTIC PERFORMANCE

The combined airflow and acoustic performance of the screened aperture may be shown in graphical form. A wall façade is modelled using standard attenuation figures for a typical cavity wall construction [9] and the measured attenuation values of the screened aperture as given in the previous sections. The composite façade attenuation in octave bands is then calculated using these figures and proportional areas of ventilator and wall construction. These attenuations are then applied to a typical road traffic spectrum [7] and the overall attenuation or $SRI_{\text{road traffic}}$ calculated in dBA by summing the unattenuated and attenuated spectrum and taking the difference.

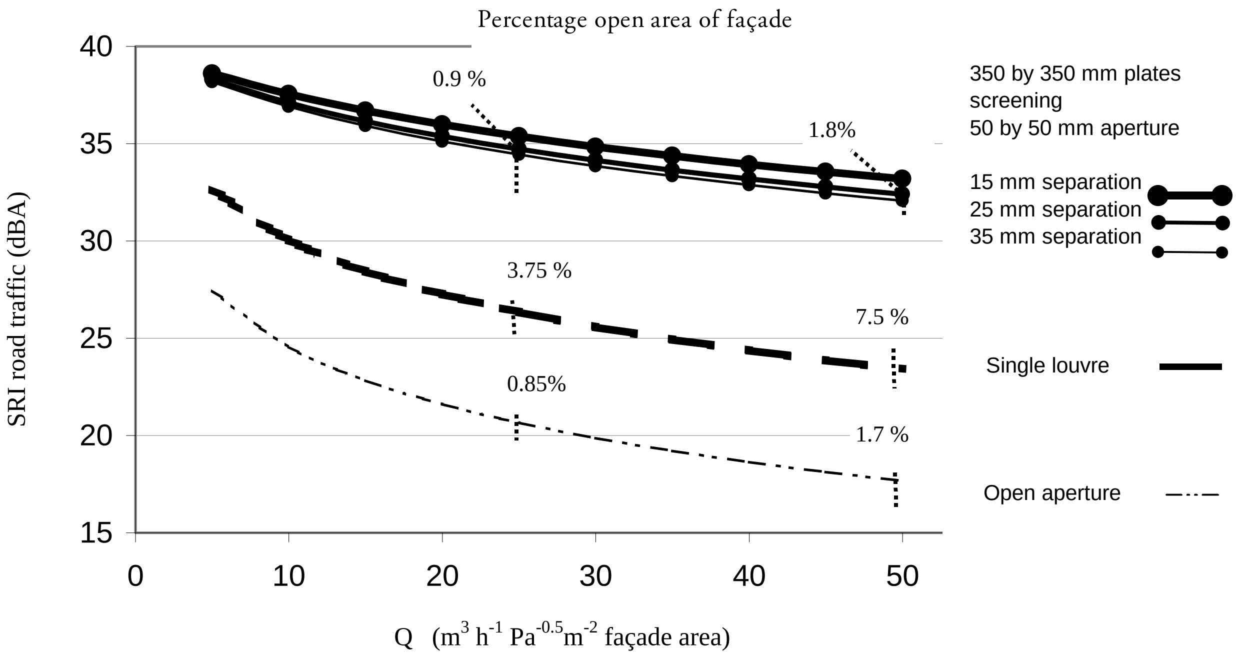

Fig 4. Projected acoustic and airflow performance of a standard cavity wall construction containing of apertures screened by absorbent backed plates - comparison with projected single louvre construction and simple open aperture [8]

The airflow in cubic metres per hour per metre squared of façade area per $\text{Pascal}^{0.5}$ may be calculated with variation in the proportional ventilator area to total façade area using the calculated flow coefficients from measurements in section III. A graph of sound insulation to road traffic noise against flow rate may then be compiled which can be applied where a fixed flow rate and sound insulation is required and from the resulting open area the required pressure differential to achieve the design conditions can be calculated or vice versa. Figure 4 depicts a typical curve which shows the projected performance of apertures to normally incident sound when screened by absorbent backed plates from sections II and III. The insertion loss results for the screens are acoustically scaled up 5 times in size as noted previously. Flow coefficients remain constant with scaling. The increase in acoustic insertion loss at low frequencies as the absorbent backed place is moved closer to the aperture apparently over-rides the increased airflow resistance to give a potentially higher Sound Reduction Index for a fixed airflow rate and pressure drop. This is achieved despite an increase in open of the ventilator required to achieve required flow rates.

In the CIBSE *Guide to Natural Ventilation in Non-Domestic Buildings* [8] it is suggested that fresh air change rates of 5-10 per hour will maximise sensible cooling in a naturally ventilated system. Calculations using half of a typically available natural pressure differential i.e. 5 Pascals [10], and applying it to a typically sized large open plan office of 1 storey height project a required air flow of 50 $m^3h^{-1}Pa^{-0.5}$ per metre squared of façade area will achieve in the region of 5 air changes per hour. Figure 4 suggests that using screened apertures this type of air change rate could be achieved in conjunction with a Sound Reduction Index (SRI) to road traffic of 33 dBA, just 7 dBA less than the case of a homogeneous wall. For equivalent flow rate this calculated SRI is 9 dBA higher than that calculated for a wall containing a single acoustic louvre and 16 dBA higher than for a simple open aperture for equivalent flow rate. It must be noted that this type of system would be an intricate mechanism to apply practically. Also it must be noted that in this case the acoustic field tested is of normal incidence and the acoustic performance may reduce in further tests at various other angles of incidence as set out in ISO 140 part V [3]. However, normal incidence may be the dominant path where the road is parallel to the façade as the sources will move further from the ventilator as the angle moves further away from normal incidence.

V. SUPPRESSING NOISE INGRESS USING ACTIVE CONTROL

Active noise control should theoretically add no flow losses to a ventilation system and should deal with low frequency noise which is the most difficult to attenuate without the use of high pressure loss dissipative attenuators. This was exemplified in section II as the low frequency performance of the passive attenuator was shown to be limited. Therefore, in combination with a low pressure loss passive attenuator, active noise control could theoretically fill in the gaps in low frequency attenuation of a ventilation system and thus simultaneously maximise levels of airflow and acoustic efficiency. In mechanical ventilation systems, noisy fans are often needed to overcome the pressure losses in the distributed system and may be sized up to overcome the large pressure losses of passive attenuators required to reduce noise levels. With reduction in low frequency noise the passive attenuation pressure losses can be vastly reduced and this is the advantage of active noise control which is most effective at low frequencies where the acoustic propagation most closely resembles the 1-dimensional propagation mentioned above. The relatively steady harmonic noise of a fan has been shown to be very efficiently suppressed by active noise control. Also the flow can be concentrated in the system such that a limited active noise control system can be applied in a single area.

While active noise control has been applied in many industrial and building services applications [11][12][13], there is no evidence in the literature of application to traffic noise.

Difficulties arise due to the nature of a traffic noise source which may be described as an inhomogeneous line source. Active noise sensors will find it difficult to track this type of field effectively. However, in a duct environment these problems are reduced as due to the simple 1-dimensional nature of the path between the sensors and actuators i.e. the reference microphone which tracks the source characteristics, the secondary source which suppresses the noise source and the error microphone which controls adaptive algorithms responding to changes in the system transfer function. Figure 5 shows an experimental set-up to test the efficiency of an active noise control system in attenuating traffic noise. Measured traffic noise is channelled into the duct via a loudspeaker. Attenuation is measured in 1/3 octave bands to reduce effects of speaker colouration which will cause error in estimated values of projected attenuation where wideband measurements are undertaken. A run of absorption is placed between the reference microphone and the secondary source to prevent standing waves building up between the source and secondary source speakers. These could cause large pressure build ups which will limit the efficiency of the secondary source. An anechoic end at the source termination makes the primary source more realistic as it is not so much affected by reflections from upstream which of course wouldn't occur when traffic noise was entering the duct from the exterior. At the error microphone the acoustic pressure is the quantity minimised but as pressure can have a spatial dependence the acoustic intensity is also measured close to the error microphone to make sure that the measured pressure attenuation also relates to power flow attenuation. The anechoic end at the measurement or 'receiver' end makes the measurement of intensity more accurate at this point. However, the measured attenuation will still relate to the attenuation available in a real system with end reflections providing the system is correctly set-up. To set the system correctly then again some damping should be provided to ensure standing waves are not too pronounced in the area of the error microphone during operation.

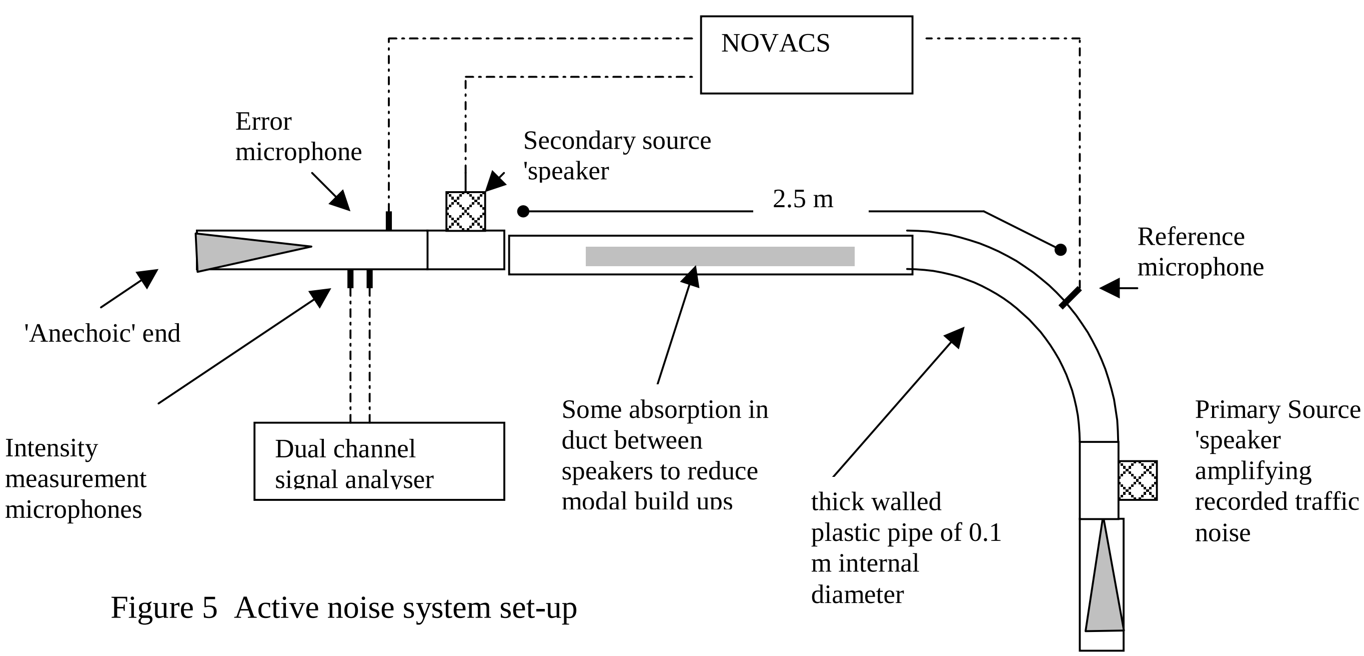

Figure 5 Active noise system set-up

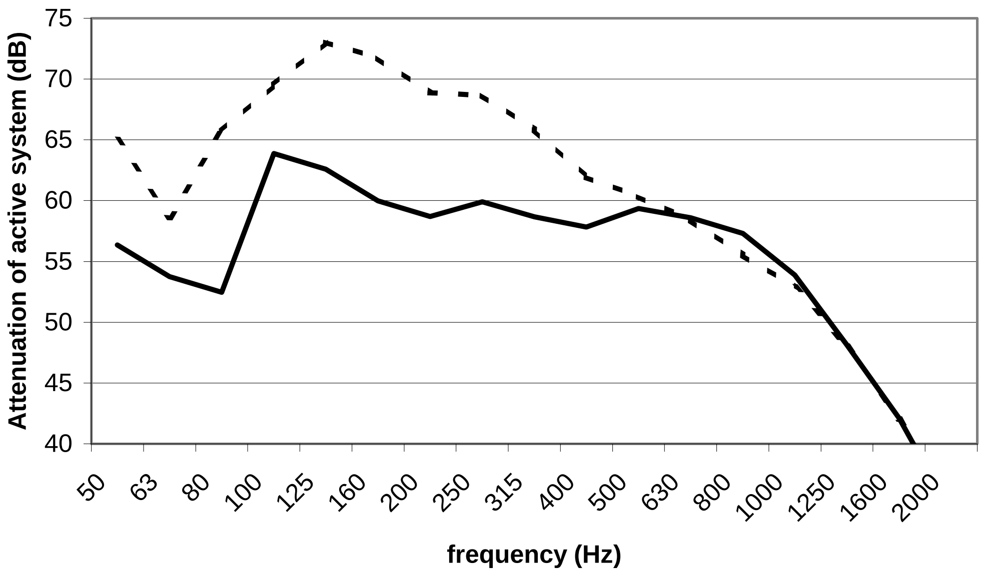

Figure 6 Measured sound intensity level in a duct due to loudspeaker amplified traffic noise recorded at a busy junction. (.....) Without active control, (____) with active control

Figure 6 shows the measured sound intensity level in the duct due to loudspeaker amplified traffic noise previously recorded at a busy junction with slow moving accelerating and decelerating traffic. The traffic noise recording is of 10 minutes duration and intensity results are averaged over this period. The averaged intensity levels are shown with and without active noise control. Attenuation ranges between 5dB and 13.5dB between 50 Hz and 315 Hz, traditionally a range where standard ventilation components will give negligible attenuation. Background noise levels were far from ideal during these measurements and coherence functions between sensor and error microphones suggested limits of active control of between 9 and 21 dB in the 50 to 350 Hz range, the limits relating to the bands of limiting attenuation performance given previously. Higher levels of attenuation could therefore be expected in conditions of lower background noise. The octave band results give 7.7 dB attenuation in the 63 Hz octave band and 8.5dB in the 125 and 250 Hz bands.

Fig. 7 shows the effect of combining the active attenuation results with the previous results for the passive screen. This would in effect amount to a screened duct inlet (ignoring the passive or reactive attenuation effect of the duct for the moment). Attenuation results applying to the scaled down frequencies from Figure 2 and applying these new acoustic figures to compile a new chart of airflow and acoustic performance. Up to 4 dBA increase in attenuation to road traffic is apparent when compared to the previous curves applied to the purely passive attenuator, and considering the maximum increase in performance would theoretically be 7 dB (bringing the performance up to that of the homogeneous wall), this is a major leap in attenuation performance. Further calculations for louvre inlets calculations have projected similar increases in attenuation.

It must be noted that a number of ducts of small cross-section will be easier to treat actively than a single duct of large cross-section. This is because the useful range of active attenuation is dictated by the cut-off frequency of the duct, i.e. frequencies of wavelength smaller than or equal to around twice the width of the largest duct cross-dimension (or diameter for circular ducts) will be untreatable using simple single channel control. This problem may be tackled using complex and more costly multi-channel control for larger ducts. However, research in this area is somewhat in its infancy compared to the single channel case, although practical examples exist [13]. Breaking the duct into smaller sections is one way of achieving control of a large cross-section using single channel sensor applied to a multi-actuator system, i.e. one speaker in each section of the duct driven by the same cancellation signal [14]. With approximately identical path conditions to all secondary source speakers this could theoretically act as a single channel control system with distributed secondary sources driven from a single channel.

CONCLUSIONS

Experimental investigations into noise control strategies for natural ventilation have suggested that the natural ventilation system need not necessarily be a major flaw to the noise insulation of a building. From acoustic and airflow measurements it was calculated that a simple ventilator design such as a screen in front of an aperture could provide up to 9 dBA greater Sound Reduction Index than a wall containing a single louvre and 16 dBA greater Sound Reduction Index than a wall façade containing a simple aperture while transmitting flow rates commensurate with limits of sensible cooling and typically available natural pressure differentials. Preliminary application of active control to a ducted system has suggested that attenuation in excess of 7.5 to 8.5 dB can be achieved for traffic noise in the octave bands from 63 Hz and 250 Hz octave. Combination of this performance with the earlier passive screen performance has suggested that such a hybrid passive/active system may be able to provide the above flow rates in combination with an SRI to road traffic of just 4 dBA less than the homogeneous wall. Problems with application of such a system are also discussed, but it may be argued the results may eventually lead to a wider range of workable natural ventilation strategies for areas of high noise concentration.

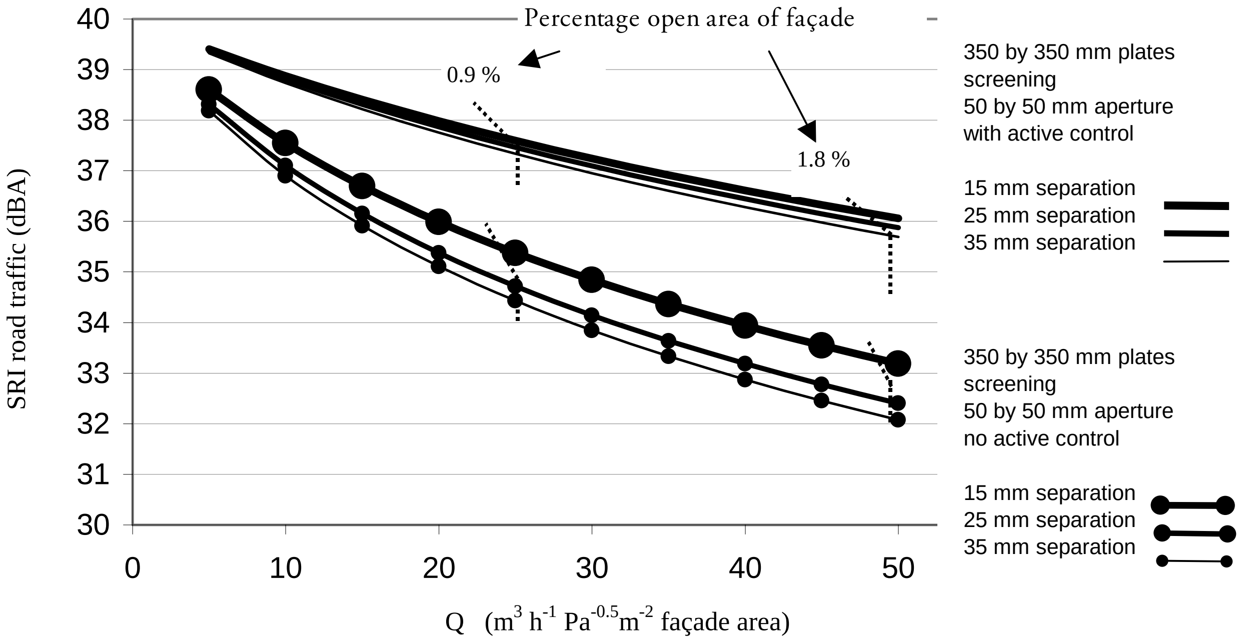

Fig 7 Projected acoustic and airflow performance of a standard cavity wall construction containing of apertures screened by absorbent backed plates - comparison showing projected increased performance of system using active noise control.

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