AIRFLOW PERFORMANCE CHARACTERISTICS OF VENTILATORS IN HYBRID VENTILATION SYSTEMS

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ABSTRACT

Part of the task in the design of ventilation systems involves selection and specification of system components - components sizes and expected performance characteristics or criteria to achieve specific ventilation objectives for anticipated environmental conditions. Careful selection of these components is required to ensure that they are able to react to changes in environmental conditions. For ventilators (air inlets and outlets) this implies that the airflow performance characteristics need to be established in relation to the widely varying pressure driving forces (in natural ventilation mode the pressure differentials are typically less than 10 Pa whilst for mechanical ventilation the driving force can be as high as 100Pa). At present "pure" hybrid ventilators are non-existent hence, a combination of natural and mechanical ventilation components are used for hybrid ventilation applications. The desire to initiate interest of manufacturers to consider development of hybrid ventilators was the motivation behind this paper. To gain some fundamental understanding of potential airflow characteristics of such hybrid ventilators this study resorted to basic elements (slots and orifices) and employed general natural ventilation theory to predict how these components would behave when subjected to the range of pressure differentials expected in hybrid ventilation applications i.e. 0 to say 100 Pa. The study investigated via a series of laboratory experiments variations in airflow performance characteristics of simple ventilators comprising rectangular slots and round-wire mesh screens. The main objectives were to investigate and quantify variations in characteristic equations of ventilators in relation to the whole range of pressure differentials expected and also with regard to changes in dimensions of the ventilator. Results obtained indicate that the characteristic equations are not only influenced by the pressure range from which they are generated but also by the constituent components of a ventilator.

KEYWORDS

Airflow, hybrid ventilation, ventilators, mesh screen, rectangular slots

1.0 Introduction

Hybrid ventilation systems are two-mode systems that combine the best aspects of natural and mechanical ventilation at different times of the day or season of the year to provide a comfortable indoor environment and good air quality. Part of the task in the design of hybrid ventilation systems involves selection and specification of system components i.e. determining component sizes and expected performance characteristics or criteria to achieve specific ventilation objectives for anticipated environmental conditions. Careful selection of these components is required to ensure that they are able to react to changes in prevailing environmental conditions. For ventilators (air inlets and outlets) in hybrid ventilation systems, this implies that the airflow performance characteristics need to be established and understood in relation to the widely varying pressure driving forces (in natural ventilation mode the pressure differentials are typically less than 10 Pa whilst for mechanical ventilation the driving force can be as high as 100Pa).

However, at present "pure" hybrid ventilators are non-existent, hence a combination of natural and mechanical ventilation components are used for hybrid ventilation applications. To gain some fundamental understanding of potential airflow characteristics of such hybrid ventilators this study resorted to basic elements such as slots and orifices and employed general natural ventilation theory to predict how these components would behave when subjected to the range of pressure differentials that would normally be encountered in hybrid ventilation applications. This served as a starting point to gaining some indication of how components such as trickle ventilators would behave when incorporated into a hybrid ventilation scheme and operated over the whole range of pressure differentials. This study investigated via a series of laboratory experiments variations in airflow performance characteristics of simple ventilators comprising rectangular slots and wire mesh screens. The main objectives were to investigate and quantify variations in characteristic equations of ventilators in relation to the whole range of pressure differentials expected, and also with regard to changes in dimensions of the ventilator.

2.0 Methodology

2.1 Airflow performance of ventilators

Current practice for estimating airflow through ventilation openings involves establishing a relationship between the pressure differential ΔP across an opening and the consequent airflow Q through that opening. The quadratic equation (Eqn. 1) is often called on in discussing problems of the leakage of airflow through small gaps. It has been suggested that the quadratic equation of the form:

$$\Delta P = \mathbf{a}Q^2 + \mathbf{b}Q \qquad \text{Eqn. (1)}$$

is more suitable for estimation of leakage area through ventilation components and provides a more accurate assessment of the flow through crack type openings than the power law [Baker *et al*, 1987]. In addition, the quadratic equation is dimensionally homogeneous and the coefficients **a** and **b** in the quadratic equation can be related to the geometry of the crack [Etheridge, 1998].

2.2 Experimental Set-up

The experimental test rig (Figure 1) used to assess the airflow characteristics of the ventilator components had an airtight plenum box measuring 1m x 1 m x 1 m to suit the requirements of the European Standard BS En 13141-1: 2004 for the size of ventilator components tested. The air handling unit consisted of a Soler & Palau type COT 130 variable speed centrifugal fan (Beatson Fans & Motors Ltd) fitted with an Excal inverter type SFS controller. The AHU was connected to the plenum chamber via galvanised steel ductwork and was capable of generating pressure differentials in excess of 100Pa across the test piece.

2.3 Components Tested

Two sets of laboratory-manufactured 300mm wide wooden rectangular slots were used to investigate the basic airflow performance of trickle ventilator type openings. Set A (Figure 2) consisted of fixed opening height (H = 12mm) slots with varying depths (D) ranging from 6mm to 36mm. Set B (Figure 3) consisted of fixed depth (D = 12mm) slots and varying opening heights (H) ranging from 6mm to 36mm. The slots were used both in isolation and in combination with a fine round-wire type insect-screen mesh with hole size 0.2mm x 0.2mm to assess the resulting airflow characteristics.

2.4 Experimental Procedure

In accordance with current practice the experimental method employed generally involved subjection of ventilator components to a pressure differential and noting the resulting airflow rate. This method is recommended in BS En 13141-1 and has widely been used by several researchers [McGrath *et al* 1984, Baker *et al* 1987, Yakubu *et al* 1991, Maghrabi *et al*, 2000] over the years.

Figure 1: Experimental test rig

Figure 2: Slot type A:- Fixed depth, varying height

Figure 3: Slot typeB:- Fixed height, varying depth

3.0 Results

Figures 4 -11 show graphical representations of the results obtained to illustrate the behaviour of the ventilators over the whole range of pressure differentials to which they were subjected. In these graphs a relative airflow (Q/Q_{12}) has been used and is in this study defined as the ratio of the airflow rate for a given slot size to the airflow rate for the slot with both depth and height equal to 12mm for a particular pressure differential. The 12mm slot was chosen as reference simply because it happened to be the intersection between the two sets of slots used in this study. Figures 4 - 7 illustrate variations of relative airflow characteristics with respect to the pressure differential for both sets of slots used in isolation and in combination with a mesh-screen. To appreciate the connection between relative airflow performance, dimensions of slots and pressure differential graphs of meshed/unmeshed slots are aligned side by side for ease of comparison.

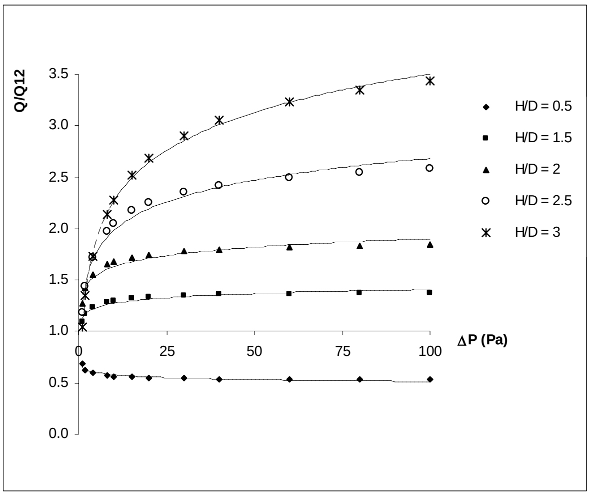

Figure 4: Q/Q_{12} as a function of ΔP for slot type A without mesh

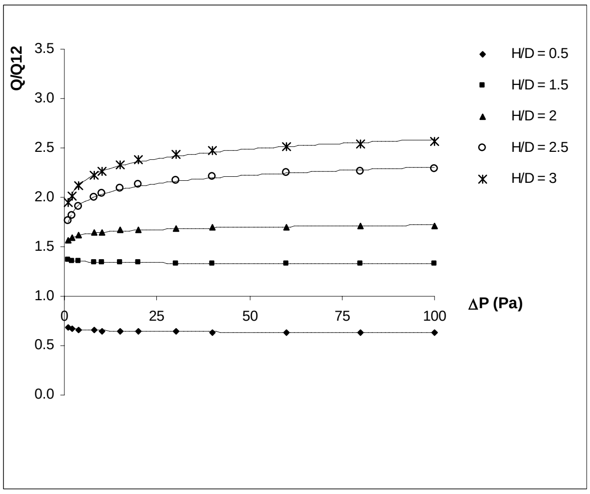

Figure 5: Q/Q_{12} as a function of ΔP for slot type A with fine mesh

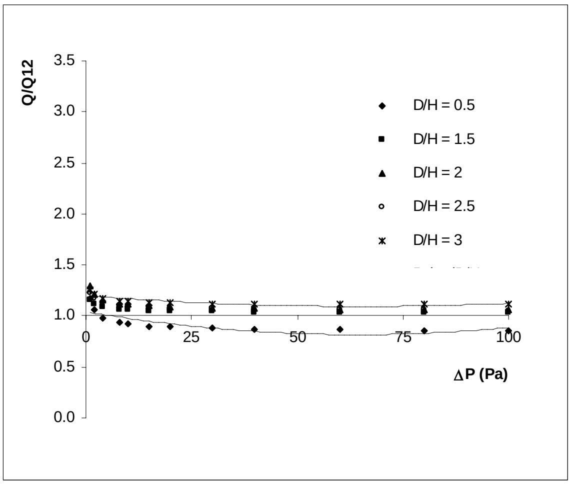

Figure 6: Q/Q_{12} as function of ΔP for slot type B without mesh

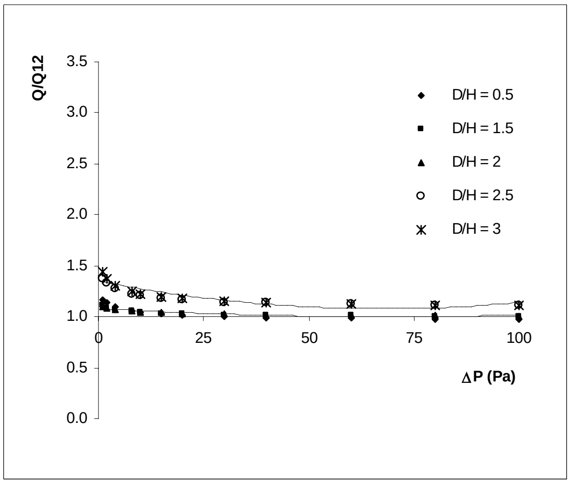

Figure 7: Q/Q_{12} as a function of ΔP for slot type B with fine mesh

Figures 8 - 11 below illustrate variations of the relative airflow (Q/Q_{12}) characteristics with respect to the height-depth ratio (type A) and depth-height ratio (type B) of slots used in isolation and also in combination with a mesh-screen. Here again graphs of meshed and unmeshed slots are aligned side by side for ease of comparison.

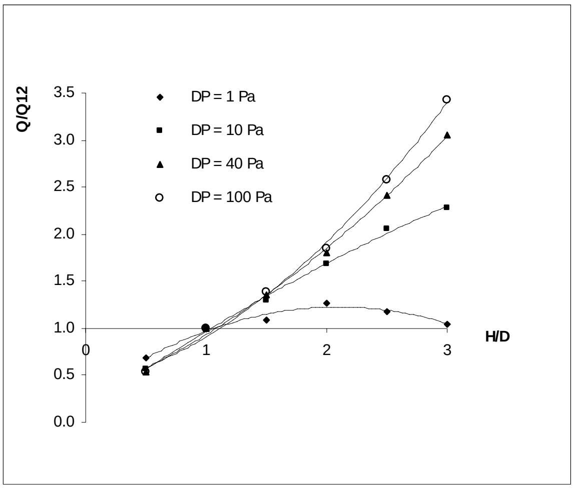

Figure 8: Q/Q_{12} as a function of H/D for slot type A without mesh

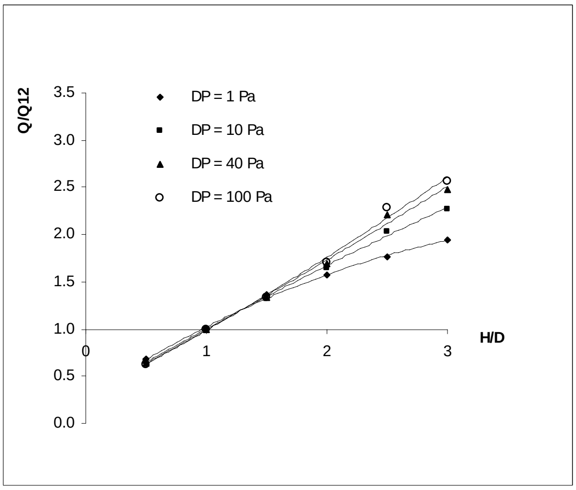

Figure 9: Q/Q_{12} as a function of H/D for slot type A with fine mesh

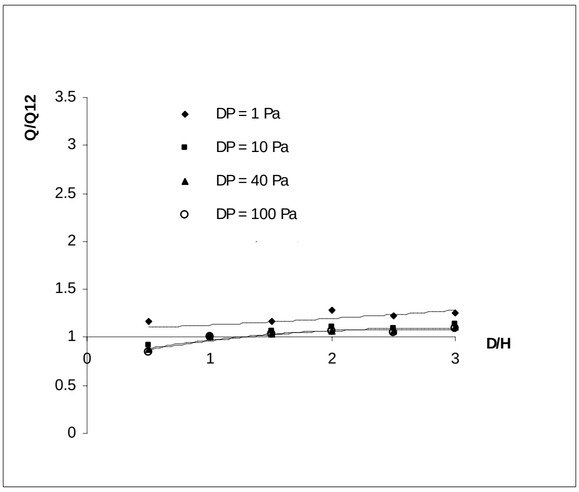

Figure 10 : Q/Q_{12} as a function of D/H for slot type B without mesh

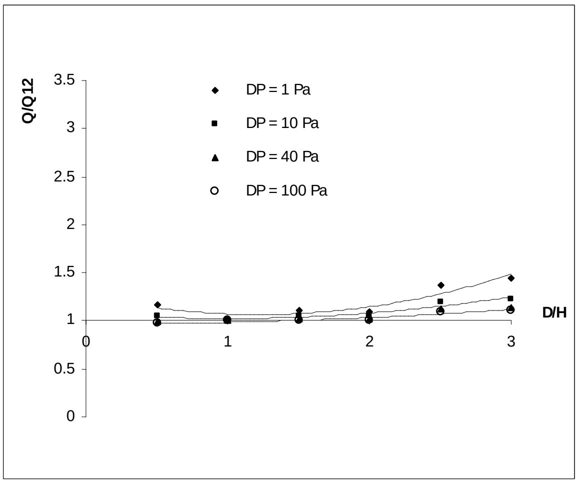

Figure 11: Q/Q_{12} as a function of D/H for slot type B with fine mesh

4.0 Discussion

Regression analysis quadratic curve fits to measured data resulted in correlation coefficients better than 0.99 in all cases considered. For slots of fixed depth and varying heights (slot type A), Figure 4 and Figure 5 showing the variation of the relative airflow (Q/Q_{12}) revealed that the cases with and without a mesh were very strongly dependant on the pressure differential at low pressures (say < 10Pa). The influence of the pressure on the relative airflow characteristic is less significant at higher pressure differentials. For slot type A it is evident that the addition of a mesh to the slots levels off the dependence on pressure at much lower values than those without a mesh. Slots of fixed height and varying depths (slot type B) revealed a more flatter relative airflow characteristic with increasing pressure differential (Figure 6 and Figure 7). Here again the effect of the pressure appears to be more significant at lower pressures.

Figure 8 and Figure 9 show the variation of relative airflow with increasing height-depth ratio for slots type A. At low values of H/D < 1 the relative flow appears to be independent of the pressure differential i.e. airflow performance at 1Pa was not much different from that at 100Pa. However, as H/D increases for the case without mesh, the dependence on pressure differential becomes significant with the lower pressure characteristic deviating away from those exhibited by higher pressure curves. It can be seen from Figure 9 that addition of a mesh to the slots reduces the deviation of the lower pressure characteristic from the trend followed at higher pressures, and converges the various characteristic curves. This suggests that a single line chosen for some intermediate pressure could be used to represent the various relative airflow characteristics without introducing significant errors.

On the other hand, for slot type B, Figure 10 and Figure 11 suggest less variation of the relative airflow with respect to the depth-height ratio. For both cases (with and without a mesh) the lower pressure characteristic (1Pa) appears to deviate away from those for higher pressures (10, 40 & 100Pa). At pressure differentials above 10Pa the graph suggests that the relative airflow performance could be represented by a single curve without introducing much errors. Without a mesh the difference between low pressure and high pressure relative airflow characteristics was approximately constant for all values of depth-height ratios. Addition of a mesh appeared to introduce a greater dependence on pressure differential for the relative airflow characteristic at depth-height ratios greater than 2.

5.0 Conclusion

From the analysis/discussion above it emerges that the characteristic equations of the simple rectangular slots and meshes are not only influenced by the pressure range from which they are derived but also by the constituent components. The results obtained suggest that by carefully selecting and combining components general solution airflow characteristics can be deduced to represent the performance of ventilators over the whole range of pressure differentials encountered in hybrid ventilation systems. To avoid significant errors the general solution could incorporate some methods to adapt resulting airflow characteristics to account for variations in pressure differentials and dimensional parameters for a given ventilator. This would ensure that the ventilator maintains a consistent airflow pattern over the whole range of pressure differentials encountered resulting in improved controllability, impact on comfort and indoor air quality. Further, although traditionally the procedure has been to establish the airflow performance of ventilator components by tests/measurements on manufactured components, by following simple analyses such as the one in this study the trend could be reversed such that ventilators are manufactured to deliver a pre-established airflow performance regime, with subsequent tests carried out only to substantiate the design.

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