Parametric analysis of the airflow performance of ventilators

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Abstract

In this study a parametric analysis was carried out of the interaction between louvres and various perforated mesh screens. This type of arrangement is common in through-the-wall ventilators used for natural ventilation in buildings. An airflow testing rig was used to examine the impact on louvre airflow performance of the meshes. The interaction of louvre geometries and blade inclinations with meshes of different hole sizes was also investigated experimentally. Airflow measurements through the individual louvre and mesh components in isolation were made and then compared to the airflow through mesh / louvre combinations. Initial results indicate that at low pressure differences the small diameter (less than 5mm) meshes were producing a discernible reduction in the airflow, but that at larger mesh diameters (15 mm) the loss was much less significant. The suitability of CFD software to predict the mesh / louvre interactions has also been investigated.

Introduction

In developed countries, such as the UK, buildings consume approximately 50% of all primary energy production. This energy is used for the heating, cooling, lighting, ventilating and activities of building occupants. Since virtually all of this energy is produced from the burning of fossil fuels then buildings also contribute around 50% of total CO_2 emissions into the atmosphere. Therefore, an important strategy in reducing global warming must be to make buildings more energy efficient. One approach to making buildings more energy efficient is to try and reduce the energy consumption associated with mechanical ventilation and air conditioning. This involves either supplementing or replacing these energy-intensive services with natural ventilation systems. Although the concept of natural ventilation is a familiar one the successful design of a modern, naturally ventilated large building is a complex and comparatively untried process. At the heart of natural ventilation systems are the facade openings that allow fresh air to flow in and stale air to flow out of a building. These openings can take the form of simple holes, openable windows, trickle ventilators and through-wall ventilators. The design and performance of these openings are critical factors in determining the success of a natural ventilation system because the natural forces that drive fresh air into buildings (the wind and/or thermal buoyancy) are very weak. The pressure difference across an opening will typically be less than 10 Pascal for a naturally ventilated building whereas for a mechanically ventilated building the pressure difference will usually exceed 100 Pascal.

Past and Current Work

A literature review of ventilator research, including a search of the AIVC database, has indicated that previous work in this area has tended to investigate either overall ventilator performance (for example [1],[2]) or individual elements such as louvres, screens and meshes in isolation (for example [3],[4],[5]). These observations are also true for the recently completed EU-funded natural ventilation research project NatVent® [6]. There does not appear to have been a systematic, parametric study of how components within a ventilator system interact with each other to impact upon the final airflow performance.

A recent study by the UK's Building Research Establishment [7] of twenty-one commercial trickle and wall ventilators revealed that the airflow performance of these devices could be more complex than might be envisaged from their relatively simple constructions. Some ventilators performed better than would be predicted from their free area, and others performed worse (*free area* is the physical size of the smallest aperture in the ventilator). The BRE study concluded that these discrepancies might arise from a poor understanding of the interactions between, among other things, internal flow paths, insect screens, filter materials, baffles and louvre blade shape / geometry. However, the BRE study was not required to investigate in a parametric manner the nature of these interactions. The main focus of this study was to carry out just such an investigation based upon a series of experimental measurements and CFD analyses.

Methodology

Basic theory of airflow through openings

The study of airflow through ventilation openings involves establishing a pressure difference **Δp** across an opening and then measuring the consequent airflow **q** through that opening. This may appear to be straightforward, but the nature of the relationship between q and Δp has been a point of debate between ventilation researchers for the last twenty-five years. Some researchers [8] feel that the relationship can be most usefully described in terms of a power law equation of the form:

$$q = c\,\Delta p^{n} \qquad (1)$$

where c and n are constants which are assumed to depend only upon the geometry of the opening.

Other researchers [9] argue that equation (1) is flawed because it is not dimensionally homogenous i.e. the constant c is not dimensionless and so its value depends upon the system of units for measurements. Also, the constant n does, in fact, vary as the flow rate varies. Instead, a quadratic equation is proposed of the form:

$$\Delta p = aq^{2} + bq \qquad (2)$$

where a and b are constants which do not depend upon the flow rate. This equation overcomes some of the drawbacks of the power law equation but is not as simple to use and does not give a value for q directly. One aim of this study was to investigate whether airflow through ventilators is better described by power law or quadratic expressions. From an aerodynamic perspective ventilators can be an interesting mix of relatively large openings (such as louvres) with flow properties independent of the flow rate (Reynolds number independent), and very small openings (such as insect meshes) that may have some Reynolds number dependence (as indicated in [10]). It was possible to study the interactions between these two regimes because of the parametric nature of the work.

Experimental Design

The experimental work used an airflow test chamber of the type used successfully in a previous project [11]. The basic elements of the chamber are shown in Figure 1.

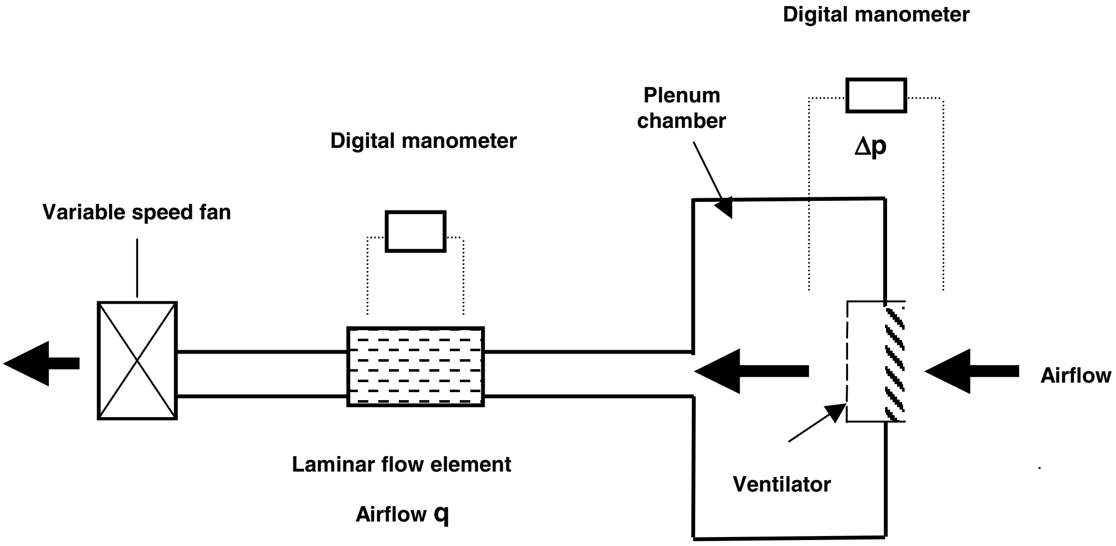

Figure 1 Schematic section through the airflow test chamber

This test chamber has been developed in general accordance with the current draft European Standard prEN 1314-1 for performance testing of air transfer devices [12], although some of the dimensions do not strictly adhere to the standard. A variable speed fan was used to generate the pressure difference Δp across the ventilator component. The value of Δp was measured using a very high quality digital manometer designed for measuring ultra low differential pressures to an accuracy of $\pm$ 0.25% of a reading. The airflow q was measured with a laminar flow element. This is a primary flow device for measuring low volume airflows. It has a linear relationship between the pressure drop across the element (measured with a second high quality digital manometer) and the flow through the element. The accuracy of a reading was within $\pm$ 0.0003 m^3/s. All of the measurement uncertainties met the limits suggested by draft European Standard prEN 1314-1. For each run a vertical velocity traverse in front of and behind the ventilator component was be taken using two precision hot wire anemometers.

Wooden louvres each with overall dimensions 320 mm x 480 mm were used in this study. The first louvre (referred to as louvre1) had 15 blades with a separation of 20 mm between the blades when they are in a horizontal position. Each blade measured 62 mm deep and 10 mm thick. The second louvre (louvre 2) had 8 blades with a separation of 50 mm between the blades when they are in a horizontal position. Each blade measured 80 mm deep and 10 mm thick.

Details of the wire mesh types used are given in Table 1:

Table 1: Details of Wire Meshes used

Mesh	Construction	Hole area (mm x mm)	Holes in 320mm x 480mm	Equivalent Open area (m2)	Free Area (%)
1	woven	0.8 x 0.8	95256	0.061	40
2	woven	1.5 x 1.5	34126	0.077	50
3	woven	3.5 x 3.5	8475	0.104	70

A typical run involved determining the flow properties of individual wire meshes. Similarly, the flow properties of an individual louvre were established. Finally, the flow properties of different combinations of meshes and louvre were measured and flow equations (power law and quadratic) produced. Such an analysis helped determine how critical mesh size was on the resultant airflows and air velocities for a particular louvre.

CFD Analysis

An important aspect of this study was to test if CFD could be used as a reliable design tool for ventilators. The accuracy of any CFD output is extremely sensitive to the assumptions made about the initial conditions and the boundary conditions. For natural ventilation in the real world these conditions are difficult to establish due to the random fluctuations in the ambient air temperatures and wind pressures. Laboratory studies are an important first step in establishing appropriate boundary conditions for CFD / ventilator analysis. The laboratory environment is much more controllable, making it possible to investigate the suitability of assumptions made regarding ventilator boundary conditions. To examine this some of the ventilator configurations were modelled using the CFD software package FLOVENT. This is an established package that is widely used by industry and for research. It was originally developed specifically for building services applications. FLOVENT has been used successfully in the past by one of the authors for studies in a related area of research [13], although the geometries involved were not as complex as in this study.

Results

Tables 2, 3, 4 & 5 and Figures 2, 3 & 4 show the measured results for meshes and the three louvre inclinations. Figure 5 shows the relationship between the mesh free areas and the resulting airflow at fixed pressure differences across louvre 1 with blades inclined at 60 deg to the horizontal. Similar results were obtained for horizontal and 30 deg louvre blade settings.

Power law and quadratic equation fits to the experimental data are summarised in Table 6.

Table 2: Airflow Q (m3/s) and Pressure Drop DP (Pa) for Louvre 1 with blades at 30 deg to horizontal

40% Free Area		50% Free area		70% Free Area		100% Free Area	
Q	ΔP	Q	ΔP	Q	ΔP	Q	ΔP
0.0351	0.590	0.0351	0.416	0.0351	0.327	0.0351	0.245
0.0335	0.548	0.0336	0.392	0.0334	0.307	0.0334	0.236
0.0314	0.498	0.0315	0.356	0.0313	0.285	0.0307	0.216
0.0296	0.455	0.0294	0.311	0.0295	0.246	0.0281	0.175
0.0266	0.403	0.0254	0.256	0.0263	0.213	0.0263	0.155

Table 3: Airflow Q (m3/s) and Pressure Drop DP (Pa) for Louvre 1 with blades at 60 deg to horizontal

40% Free Area		50% Free area		70% Free Area		100% Free Area	
Q	ΔP	Q	ΔP	Q	ΔP	Q	ΔP
0.0351	1.398	0.0351	1.205	0.0350	1.072	0.0351	1.072
0.0335	1.256	0.0336	1.101	0.0335	1.027	0.0334	0.952
0.0315	1.146	0.3158	1.010	0.0316	0.927	0.0313	0.845
0.0296	1.033	0.2984	0.923	0.0295	0.840	0.0294	0.750
0.0245	0.761	0.0278	0.803	0.0276	0.738	0.0263	0.622
0.0226	0.638	0.0230	0.598	0.0224	0.517	0.0240	0.528

Table 4: Airflow Q (m3/s) and Pressure Drop (Pa) for Louvre 1 with Horizontal Blades

40% Free Area		50% Free area		70% Free Area		100% Free Area	
Q	ΔP	Q	ΔP	Q	ΔP	Q	ΔP
0.035	0.512	0.035	0.315	0.035	0.235	0.035	0.180
0.034	0.424	0.034	0.283	0.034	0.203	0.033	0.169
0.031	0.404	0.031	0.250	0.031	0.184	0.031	0.148
0.029	0.368	0.029	0.226	0.029	0.165	0.029	0.107
0.025	0.293	0.024	0.181	0.025	0.127	0.024	0.098
0.020	0.215	0.019	0.129	0.020	0.076	0.019	0.063

Table 5: Airflow Q (m3/s) and Pressure Drop DP (Pa) for Meshes of Different Free Areas

40% Free Area Mesh		50% Free Area Mesh		70% Free Area Mesh	
Q	ΔP	Q	ΔP	Q	ΔP
0.035	0.403	0.035	0.192	0.035	0.146
0.034	0.342	0.034	0.180	0.034	0.113
0.032	0.335	0.032	0.169	0.031	0.108
0.029	0.301	0.029	0.155	0.029	0.096
0.025	0.253	0.025	0.125	0.025	0.064
0.023	0.211	0.023	0.113	0.023	0.059
0.021	0.192	0.020	0.097	0.021	0.056

Table 7: Comparison between CFD and Experimental Results for Louvre 2 at 0.029m3/s

Blade angle (deg)	Mesh Free Area (%)	Exp ΔP (Pa)	CFD ΔP (Pa)	% Difference
0	100	0.087	0.097	12
	50	0.187	0.123	34
30	100	0.107	0.097	9
	50	0.241	0.181	24
60	100	0.377	0.447	18
	50	0.493	0.394	20

Table 6: Comparison between Power Law and Quadratic Equation fit for Louvre 1 at different Blade Angles

Louvre Blade Angle (deg)	Mesh Free Area (%)	Power Law			Quadratic Equation		
		c	n	R	a	b	R
0	40	59.31	1.439	0.9816	216.83	6.196	0.9690
	50	37.48	1.438	0.9937	131.45	4.114	0.9915
	70	179.74	1.987	0.9914	176.36	0.358	0.9889
	no mesh	62.11	1.751	0.9595	127.59	0.632	0.9589
30	40	73.84	1.443	0.9985	237.60	8.423	0.9981
	50	64.23	1.504	0.9979	192.31	5.155	0.9981
	70	87.92	1.664	0.9935	181.89	3.110	0.9909
	no mesh	81.87	1.722	0.9917	146.09	2.116	0.9824
60	40	438.99	1.720	0.9977	852.73	9.555	0.9973
	50	308.71	1.657	0.9985	687.78	10.091	0.9982
	70	287.81	1.662	0.9972	603.11	10.151	0.9950
	no mesh	476.54	1.826	0.9975	752.70	3.725	0.9969

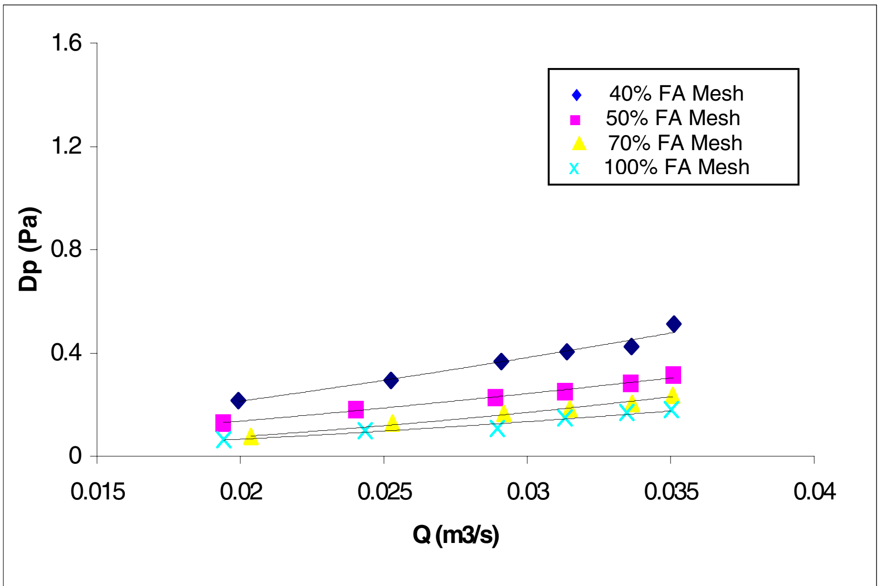

Figure 2: Louvre 1 with Horizontal Blades

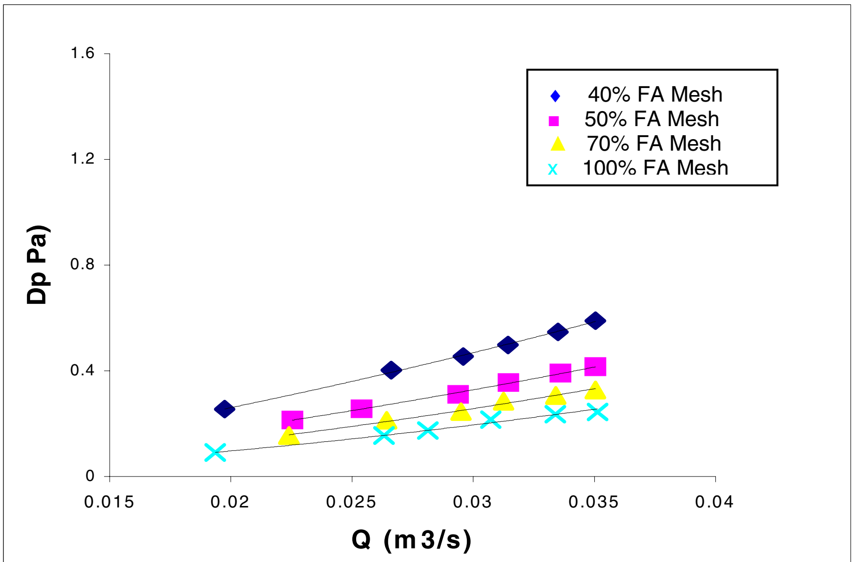

Figure 3: Louvre 1 with Blades at 30 deg to Horizontal

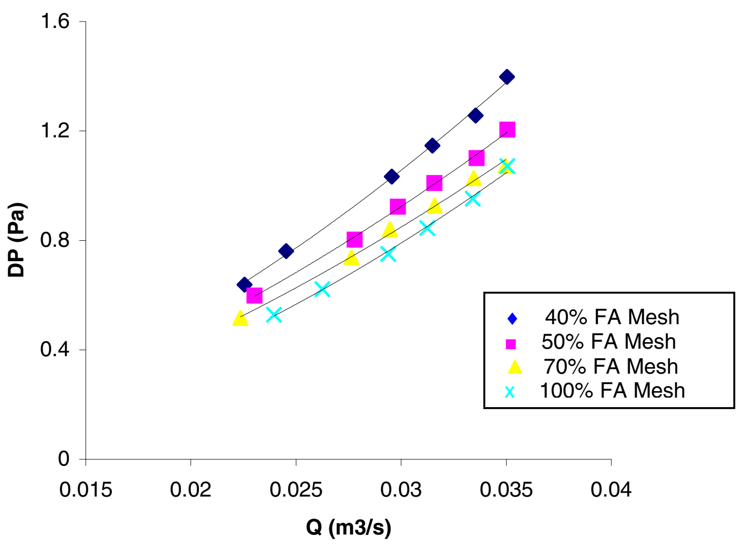

Figure 4: Louvre 1 with Blades at 60 deg to Horizontal

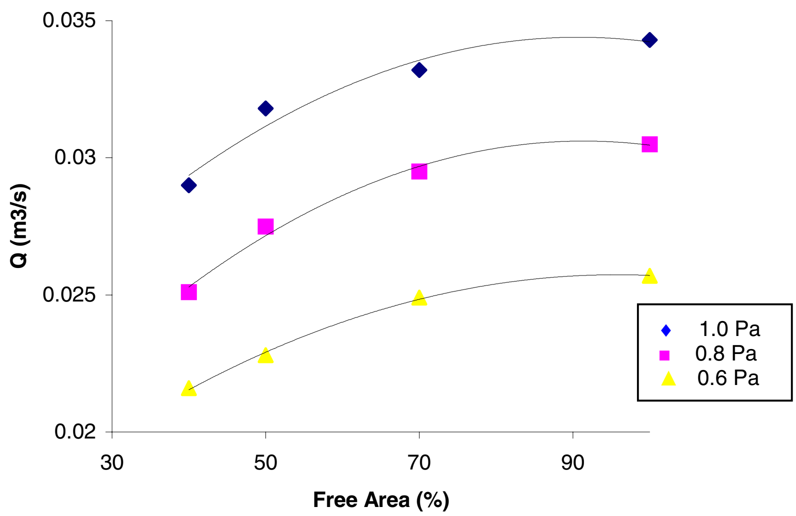

Figure 5: Airflow Q (m3/s) and Mesh Free Area (%) at Different Pressure Drops for Louvre 1 with Blades at 60 deg to Horizontal

Discussion

Comparison of airflow properties of louvre/mesh combinations against simple addition of louvre and mesh properties in isolation show that the influence of the mesh generally decreases with increasing louvre blade inclination.

For the three louvre blade inclinations considered, the simple addition of individual louvre and mesh ΔP values was found to give a bigger ΔP than the combined louvre/mesh combinations. For a mesh with 40% free area, this varied from 15% for horizontal blades to 7% at 30 deg blade inclination and 1.4% at 60 deg. For the 50% free area mesh the proportions were 24%, 6% & 0.01% whilst those for the 70% free area mesh were 39%, 13% and 2.8% respectively.

Close examination of Table 6, which gives a comparison between the power law and quadratic equation, shows that although the correlation coefficients were very similar for the two cases, the power law fitted the measured data slightly better than the quadratic formulation. This was the case for all louvre/mesh combinations and blade inclinations. The correlation coefficient ranged from 0.9595 to 0.9985 for the power law whilst the quadratic equation had the correlation coefficients ranging from 0.9589 to 0.9982.

Figure 5 shows the effect of varying the mesh free area on louvre airflow performance. There was an appreciable change in the louvre airflow as a result of varying the free areas up to about 70% whilst changes in airflow at higher free areas were relatively low.

Table 7 shows a comparison between experimentally measured pressure drops and CFD predicted values for a typical airflow of $0.029m^3/s$. The difference between the values ranged from 9% to 34%. For 50% mesh free area differences were found to be much higher than the values for 100% free area. This can be attributed to difficulties in achieving a fully converged solution for the 50% mesh free area within the available time.

Conclusions

This parametric study has highlighted the effect of meshes on louvre airflow performance. The results indicate that the airflow performance of louvre/mesh combinations are not obtained by direct addition of the properties of louvres and meshes in isolation. This suggests rather complex airflow properties resulting from the interaction between louvre/mesh combinations.

An initial study comparing experimental results with CFD predicted values of ΔP suggest that for the louvre/mesh combinations the agreement improves as louvre inclination angle increases. However, the percentage differences are quite large and further work is needed to improve the CFD model.

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