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Ventilation Air Flow Through Window Openings in Combination with Shading Devices

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Synopsis

In the UK the increased use of natural ventilation in buildings is being encouraged, particularly during hot weather as an alternative to air conditioning or mechanical ventilation. In order to take advantage of this option building designers need to be able to estimate potential air flows. Conventional calculation methods assume windows to be simple openings, however in practice the situation is more complex since during hot weather the opening is likely to be shielded by some form of solar shading device. This paper reports the results of a laboratory based investigation of the pressure difference-flow relationship for air movement through windows when a venetian blind is also in position. A variety of window opening variations and blind angles have been tested. The results indicate a significant reduction in air flow when blinds are in use in the closed position (angle 85^{o}); the results for partially closed position (45^{o}) show little reduction in flow. The form of the window opening also has an important effect. Care must therefore be taken in setting blind angles so as to avoid reducing beneficial natural ventilation air flow whilst maintaining shading.

1. Introduction

Many modern office buildings suffer the risk of overheating, often during the summer months but also potentially at other times of the year. The causes of this are many: high solar gain; high internal heat production; extensive use of modern office equipment; high densities of occupation. There has however only been one traditional remedy: air conditioning. Air conditioning has a number of negative attributes: it is more costly to install and operate; the refrigerant gases may have the potential to damage the atmosphere if released; and it requires substantial amounts of energy to function with consequent emissions of carbon dioxide from fossil fuels used as the primary energy source. In recent times building designers have become more aware of the potential for overheating caused by large areas of glazing and similar features in buildings and many are attempting to reduce such problems. Even with this change to more climate sensitive design, overheating risk persists and alternatives to air conditioning and mechanical ventilation systems are sought. Clearly one possibility in suitable climates is the increased use of natural ventilation. If the potential of this option is to be fulfilled, designers must have access to calculation/estimation techniques for predicting natural ventilation air flows. The information required is available only for relatively straightforward options at present (plain openings or cracks) and therefore there exists a need for more data, particularly on non-standard openings.

The investigation reported in this study attempts to build on some earlier work and provide help in the specific situation of air flow through partially opened windows which are also shielded against direct solar heat gain by devices such as venetian blinds.

2. Background

Flow relationships for air movement through buildings have been studied for many years. The basic aim of such work being the ability to more accurately predict and assess such flows by calculation and simulation rather than experimentation on every building (though some such experiments do have a role and are valuable in their own right). Knowledge of air flow rates enables more accurate estimation of energy flows and comfort levels.

The power law relationship has been widely used to express the link between pressure differential and volume flow rate with the general form :

$$Q = c\Delta P^n \tag{1}$$

(where Q is the air flow rate, m^3s^{-1}; ΔP is the pressure differential, Pa; n and c are constants). This algorithm is widely used, for example by ASHRAE [1], in the form of equation 1 or in its reciprocal format as $\Delta P = cQ^n$. Studies over many years, going back to the work of Dick [2] have derived this form of empirical relationship for flow through openings other than cracks and have normally found the exponent, n, to take a value of 0.5. The power law relationships of the type of equation 1 have been criticised however for their lack of dimensional homogeneity. Also the square law does not reflect the relationship for flow through narrow cracks. A quadratic relationship of the form :

$$\Delta P = aQ^2 + bQ \tag{2}$$

(where a and b are constants), has been found to be more useful for description of crack flow and more acceptable from a dimensional analysis point of view [3]. More details of air flow algorithms can be found in the work of Liddament [4] for example.

The investigation described in this paper attempts to use such relationships in the case of window openings which are partially blocked by venetian blind shading devices. In this, the work of Yakubu and Sharples [5] which dealt with modulated louvres, is built upon. That study differed in a number of important aspects from the work described here. They were concerned with flow across a louvre system in which the louvres were both thicker (5mm) and wider (100mm) than venetian blinds, with a spacing of 95mm. An attempt was made to apply the flow equations based on the theory of flow through a series of parallel plates; however the experimental results did not substantiate such a theory in the form proposed.

In the reported results of that study, the quadratic form of the flow relationship was found to produce more acceptable results than the power law, however the constant, b, (see equation. 2) took small values with the result that ΔP was almost entirely dependent on the Q^2 term. This would indicate a square law relationship which is characteristic of a turbulent flow. Yakubu and Sharples also found that with louvre inclinations up to about 45° that there was no significant decease in flow for the same pressure difference.

3. Experimental Work

The work described in this study was carried out in a controlled wind tunnel laboratory environment. The situations investigated were chosen to represent a number of commonly found combinations of window opening and venetian blind position. Results reported here deal with the situations of window fully open (100% open surface area) and three variations of partially closed window : 67% open; 50% open and 33% open. Each of these four options was tested in combination with four blind configurations : blind retracted; blind with horizontal fins (angle 0°); blind with fins at 45° (partially closed), and 85° (fully closed). The fins each measured 910mm wide, 50mm depth, 0.25mm thick with a spacing when horizontal of 40mm.

The wind tunnel air flow was controlled by a variable flow axial fan and the flow rate monitored and measured by a vane anemometer centrally positioned and calibrated upstream of the working section. Pressures were measured by means of a high resolution differential pressure manometer which was also calibrated at the start of the investigation. Pressure tapping positions were chosen with care and were situated approximately one "duct" diameter upstream and immediately downstream of the window/blind obstruction. Several options for such positioning were considered and tested before settling on this regime which appeared to give most accurate and repeatable results. A number of measurements of pressure differential and flow rate (typically 9 or 10) were made for each window opening and blind combination. Flow rates up to about 2.5 ms^{-1} were employed; beyond this physical disturbance to the blinds occurred.

4. Results

The results were analysed with respect to the two principal relationships (see equations 1 and 2) by means of propriety curve fitting packages. Both gave very good correlation coefficients. More details of the results and procedures can be found in Georgiadis[6]. Tables 1 and 2 below summarise the relationships derived.

Table 1 Power Law Flow-Pressure Relationships

Blinds Configuration	Percentage of Open Surface Area: 100 %	67 %	50 %	33 %
No blinds	$Q=0.634\Delta P^{0.455}$	$Q=0.354\Delta P^{0.479}$	$Q=0.269\Delta P^{0.481}$	$Q=0.170\Delta P^{0.483}$
Blind angle 0°	$Q=0.636\Delta P^{0.433}$	$Q=0.360\Delta P^{0.474}$	$Q=0.278\Delta P^{0.475}$	$Q=0.185\Delta P^{0.462}$
Blind angle 45°	$Q=0.516\Delta P^{0.441}$	$Q=0.346\Delta P^{0.453}$	$Q=0.280\Delta P^{0.462}$	$Q=0.189\Delta P^{0.452}$
Blind angle 85°	$Q=0.275\Delta P^{0.485}$	$Q=0.212\Delta P^{0.520}$	$Q=0.174\Delta P^{0.486}$	$Q=0.153\Delta P^{0.471}$

Table 2 Quadratic Flow-Pressure Relationships

Blinds Configuration	Percentage of Open Surface Area: 100 %	67 %	50 %	33 %
No blinds	$\Delta P = 3.204\,Q^2 - 0.460\,Q$	$\Delta P = 9.502\,Q^2 - 0.786\,Q$	$\Delta P = 15.439\,Q^2 - 0.235\,Q$	$\Delta P = 39.411\,Q^2 - 0.852\,Q$
Blind angle 0°	$\Delta P = 3.560\,Q^2 - 0.790\,Q$	$\Delta P = 9.048\,Q^2 - 0.462\,Q$	$\Delta P = 15.048\,Q^2 - 0.589Q$	$\Delta P = 38.329\,Q^2 - 1.812\,Q$
Blind angle 45°	$\Delta P = 5.336\,Q^2 + 0.878\,Q$	$\Delta P = 11.294\,Q^2 - 1.025\,Q$	$\Delta P = 16.524\,Q^2 - 1.197\,Q$	$\Delta P = 40.758\,Q^2 - 3.234\,Q$
Blind angle 85°	$\Delta P = 13.254\,Q^2 + 0.338\,Q$	$\Delta P = 17.507\,Q^2 + 1.751\,Q$	$\Delta P = 33.790Q^2 + 0.600\,Q$	$\Delta P = 53.174\,Q^2 - 1.951\,Q$

The results are shown in graphical format in Figures 1 to 4 for the power law relationships.

An examination of Table 2 shows that the term bQ has much less significance than the aQ^2 term indicating the square power law relationship to be the predominating factor. This would also be in agreement with the existence of a developed turbulent flow regime for the situation under study (which is as expected from personal observation).

The results are also in agreement with the general finding from the work of Yakubu and Sharples in that the reduction in flow due to the obstruction caused by the blinds is significant only above fin angles of 45°. This is particularly well illustrated by Figures 1 to 4. One unexpected phenomenon was in the apparent increase in flow found when blinds were lowered into position (at 0° and some 45° fin angles) by comparison with the "no blinds" case. This appears to occur in the combinations where the window opening is in a partially closed mode and may be the result of the blinds actually aiding the flow through the window constriction.

5. Conclusions and Recommendations

The study reported in this paper shows that thin cross-section shading devices such as venetian blinds may be used up to fin angles of about 45° without any significant reduction in natural ventilation air flows. Indeed there is some evidence to suggest that the use of suitably angled blinds may actually enhance air flow through partially opened windows. This phenomenon is certainly worthy of further investigation. In this respect it concurs with a previous study which suggested conventional flow equations may be insufficient to explain flow through shading devices where a number of parallel flows occur.

Further work on additional window and blind combinations is currently underway and it may prove useful to attempt to correlate the findings with a computational fluid dynamics analysis.

If shading devices with angled fins are to be used in conjunction with natural ventilation flow openings then care should be taken to ensure that the angle, width of fin and sun altitude are carefully considered to optimise the benefits.

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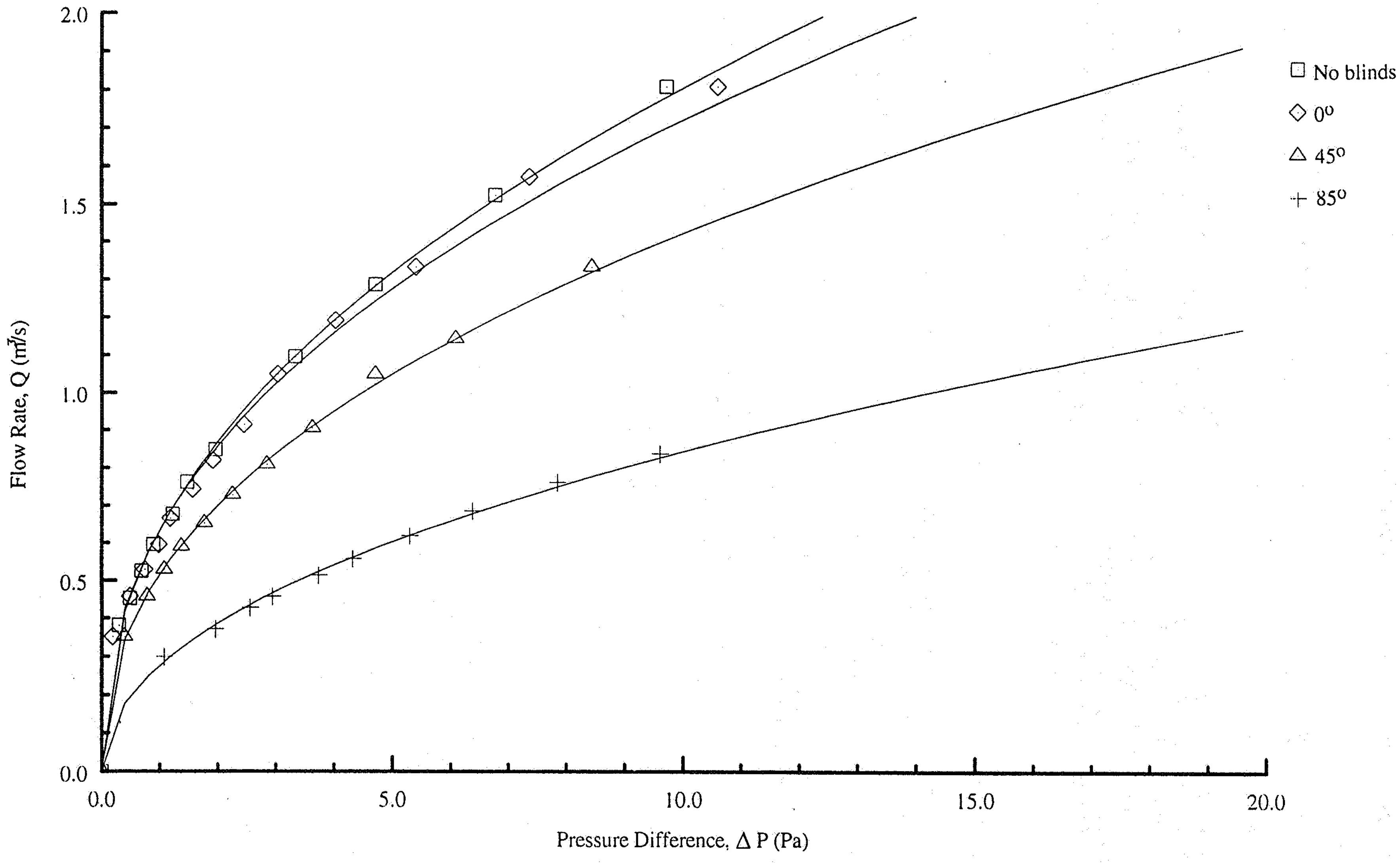

FIGURE 1: RESULTS FOR UNOBSTRUCTED WINDOW (100% FREE AREA)

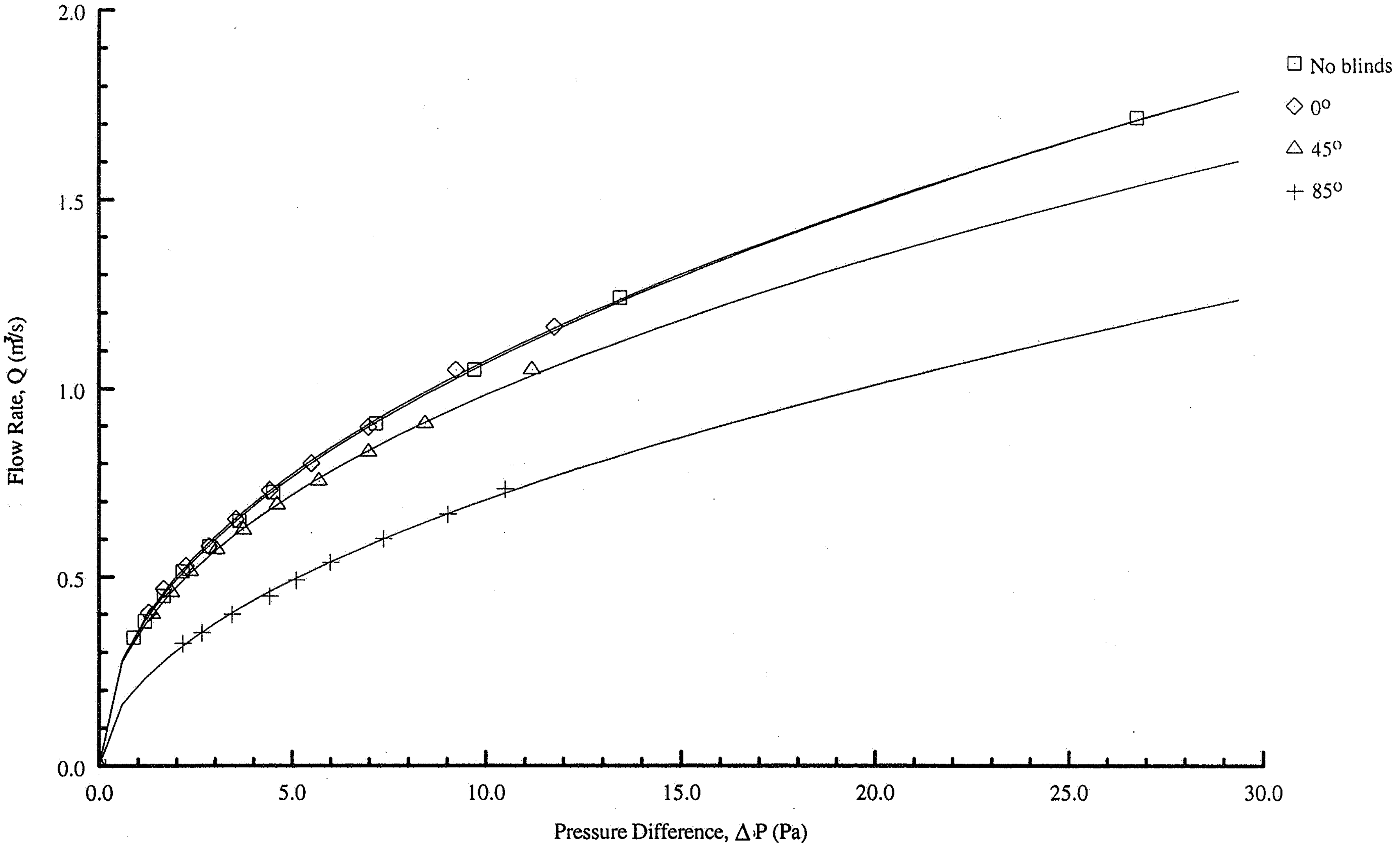

FIGURE 2: RESULTS FOR PARTIALLY OBSTRUCTED WINDOW (67% FREE AREA)

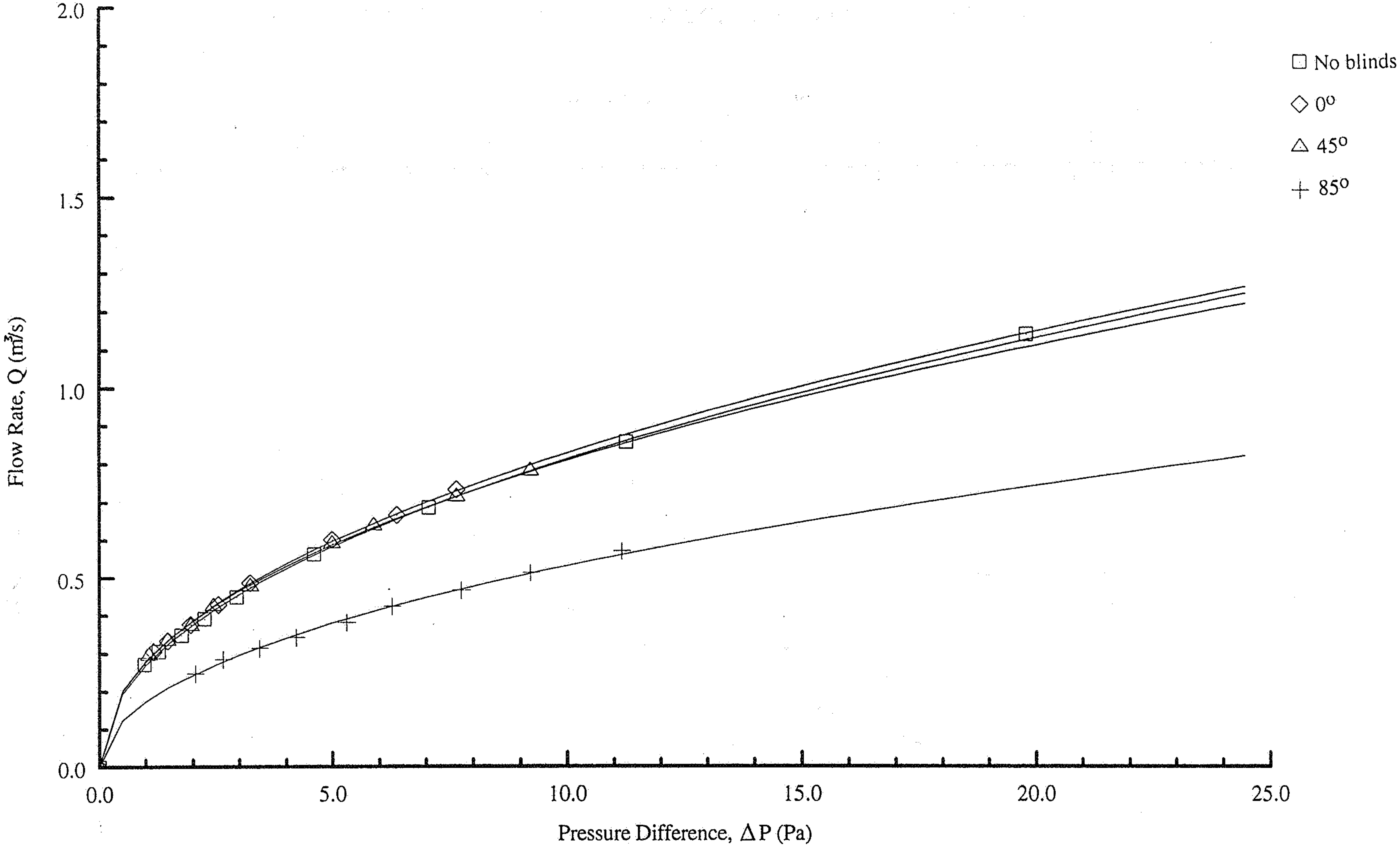

FIGURE 3: RESULTS FOR PARTIALLY OBSTRUCTED WINDOW (50% FREE AREA)

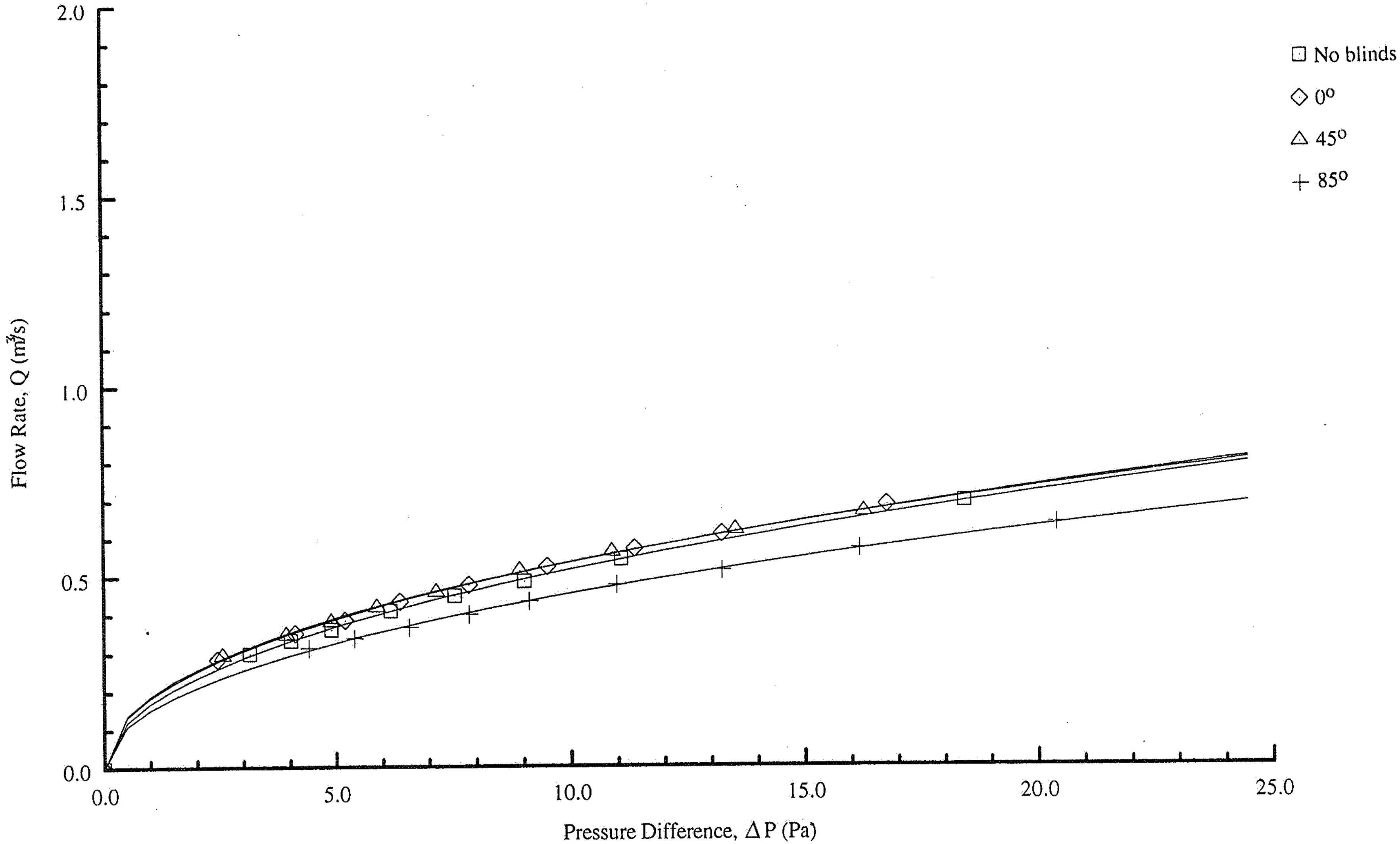

FIGURE 4: RESULTS FOR PARTIALLY OBSTRUCTED WINDOW (33% FREE AREA)