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EXPERIMENTAL PASSIVE STACK SYSTEMS FOR CONTROLLED NATURAL VENTILATION

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The modern trend towards more airtight energy efficient housing requires additional care in providing controlled ventilation. Passive Stack Ventilation (PSV) is one way of providing the necessary control. The Building Research Establishment (BRE) is carrying out research into the performance of PSV systems in dwellings. Several different PSV systems were installed in a test house and the flow velocity through them measured under a range of meteorological conditions. The results of these tests are presented and the effect of bends in the duct and duct diameter are discussed.

INTRODUCTION

Until fairly recently the majority of U.K. houses were built with chimneys and many ventilation problems were with too much rather than inadequate ventilation. The modern trend towards more airtight, energy efficient housing, with no open chimneys or flues, can lead to condensation and indoor air quality problems unless care is taken to provide an alternative means of ventilation. One possible solution could be to reintroduce the chimneys but in a form known as a passive stack ventilation system (PSV). By placing them in the moisture producing rooms i.e.. kitchens and bathrooms, use can be made of the natural stack effect to ventilate these rooms, thereby removing the warm moist air, without the use of mechanical fans. The advantages of using PSV systems are their lack of noisy fans, little maintenance, no direct running costs, no moving parts to break down and, if installed when the dwelling is built, cheapness of installation.

The Building Research Establishment (BRE) carried out some research into PSV in the late 1950's, but the systems used very large, square section stacks which bore little resemblance to modern installations, hence there was not much interest in their use. Interest in the use of PSV was revived in the 1970's by de Gids and den Ouden (1) and later work was carried out in the 1980's by Johnson and Pitts (2), Johnson Gaze and Brown (3) and Edwards and Irwin (4). Stephen and Uglow (5) produced an information paper based on current knowledge, on the design and installation of PSV systems.

As part of a research programme to test their performance the Building Research Establishment has set up various passive stack ventilation systems in a test house, using different duct materials in a range of diameters and configurations, by using the same dwelling for all the tests, a direct comparison of systems can be obtained. This paper describes the various systems and their respective performances.

Description of test house and ventilator systems

The house used to test the various passive stack ventilator systems is an end of terrace, timber framed building with a roof pitch of 42 degrees. It is situated at the Building Research Establishment, Garston, in a position of fairly open ground to the South and West with trees to the North and office blocks some distance to the East see Figure 1. The room in which the systems were installed is the kitchen/diner, having a volume of 35 m^3.

Two stack ventilator configurations were used, the first was a straight duct from the kitchen ceiling through the bedroom above and the attic, terminating at just above ridge height with a weatherproof terminal. The second configuration had two 45 deg. bends in the attic section to enable the duct to be connected to a ridge terminal, see Figure 2. The stack was lagged with fibreglass quilting where it passed through the attic to reduce heat losses and possible condensation problems within the stack.

Two stack diameters were used, 155 mm and 100 mm, and two different materials, smooth rigid plastic and flexible plastic on a wire spiral. A number of different roof terminals and ceiling diffusers were used and their performances compared. The systems which will be reported on here are the four basic systems using rigid duct material in two different configurations and diameters. A comparison will also be made of the results obtained from two of the systems with those from similar systems using flexible ducting.
Table 1 lists the systems reported on.

TABLE 1 - Passive stack ventilation systems tested.

SYSTEM	DIAMETER (mm)	MATERIAL	CONFIGURATION
1	155	RIGID	BENDS
2	155	RIGID	STRAIGHT
3	155	FLEXIBLE	BENDS
4	155	FLEXIBLE	STRAIGHT
5	100	RIGID	BENDS
6	100	RIGID	STRAIGHT

Data collection

The various parameters which were monitored are as follows :

- Wind speed
- Wind direction
- External temperature
- Internal temperature (3 positions)
- Duct temperature (2 positions)
- Flow velocity in duct

Wind speed and direction were measured adjacent to the test house at a height of 10 metres. External temperatures were taken from inside a Stevenson Screen on the North side of the house. Internal temperatures were taken in the kitchen, bedroom and attic. Duct temperatures and velocity were measured at the positions shown in Figure 2. Duct velocity was measured using a Dantek low velocity flow analyser. This cannot indicate flow direction, so to detect any reverse flow pitot-static tubes were installed in the stack, one facing down to measure upward flow and another facing up to measure downward flow. (No prolonged reverse flow was actually detected by this method).
Monitoring took place over several weeks for each different system, the duration depending on weather conditions. The data covered as wide a range of wind speeds and directions as possible. A range of temperature differences between inside and outside the house was achieved by the use of electric panel heaters. The case of the outside air temperature being higher than inside was not considered relevant as in warmer weather windows are more likely to be open.

All data was collected using a programmable datalogger. With the exception of wind speed, all parameters were scanned once every 10 seconds and then half-hourly averages calculated and logged on magnetic tape. The wind speed recorder works on the 'pulse count' principle and therefore just the half-hourly average was logged.

Analysis of data

The data from each system was transferred from tape to computer disks and then read into a spreadsheet computer program.

For each system, the data was sorted into four wind direction quadrants: 045°- 135°, 136°- 225°, 226°- 315°, 316°- 045°. See Figure 1 for these directions with respect to the test house.

Initially, graphs were drawn of the stack velocity against temperature difference, wind speed and wind direction, for typical results see Figures 3a - 3c. The stack velocity would appear to be largely dependent on temperature difference although not directly proportional to it, see Figure 3a. On examination of the figures plotted in Figure 3a it is found that the stack velocity is in fact proportional to the square root of the temperature difference, indicating turbulent flow see Figure 4. To see what effect, if any, wind speed and direction had, the stack velocity was divided by the square root of the temperature difference and then plotted again against wind speed and direction. At wind speeds below around 2 m/s the wind had very little effect but had an increasing effect at higher wind speeds see Figure 5. The data splits into two trend lines above 2 m/s, the higher set of data occurs at a particular wind direction, this is possibly due to the configuration of the PSV ridge terminal, dwelling roof and surrounding terrain. Wind direction appears to have only a slight effect, see Figure 6, the high points around 220 - 230 degrees being those of the upper trend line in Figure 5. Many of the higher wind speeds recorded are from the south west, this being the prevailing wind direction for the area and also the most open in relation to the test house. Higher wind speeds from other directions did not cause similar increases in stack velocity. Figure 7 shows the relationship between the square root of the temperature difference and stack velocity for wind speeds less than 2 m/s.

In order to compare the various systems, regressions were calculated, using the spreadsheet, of :

1) stack velocity with wind speed and square root of temperature difference

2) Stack velocity with square root of temperature difference (for wind speeds less than 2 m/s).

The predicted mean stack velocities and flows from the first regressions for a temperature difference of 10 degrees and wind speed of 4 m/s are shown, see Figures 8 and 9 and Table 2.

TABLE 2 - Comparison of velocities and flows for different systems.

SYSTEM	VELOCITY (m/s)					FLOW (m^3/hr)				
	WD 1	WD 2	WD 3	WD 4	mean	WD 1	WD 2	WD 3	WD 4	mean
1	0.56	0.49	0.77	0.46	0.57	36.4	31.6	49.4	29.9	36.8
2	1.07	1.28	1.55	0.69	1.15	69.0	82.6	100.2	44.3	74.0
3	0.61	0.61	0.71	0.45	0.59	39.3	39.1	45.8	29.1	38.3
4	0.71	1.46	1.60	0.73	1.12	46.0	93.9	103.2	46.8	72.5
5	0.71	0.98	1.15	0.70	0.88	18.9	26.2	30.9	18.7	23.7
6	1.10	1.60	1.83	0.68	1.30	29.4	42.9	49.2	18.1	34.9

The effect of putting bends in the system can be seen by comparing systems 1 with 2, 3 with 4 and 5 with 6. The flow is reduced by the bends, by as much as 50%, especially with the wind in the prevailing direction. By comparing systems 1 with 5 and 2 with 6 the effect due to stack diameter can be seen: The velocities measured in the smaller diameter stack are slightly higher than those for the larger diameter. This is the opposite of what might be expected and is probably a Reynolds No. effect. In terms of volume flow rate however, the flows in the larger stack are around twice those obtained in the smaller stack for a straight configuration and 50% higher for one with bends. The flow in the straight ducts is approximately proportional to the area and the pressure loss due to friction in the duct is of the same order as the entry and exit losses i.e. the duct is very smooth. Systems 3 and 4 are the same configurations as systems 1 and 2 but are of flexible ducting instead of rigid. The flexible ducting appears to have little or no effect on flow, see Figures 8 and 9. The reason for this, and indeed the apparent smoothness of the ducts is that the flow is at relatively low Reynolds numbers $Re<10^4$ and thus in the fluid dynamically smooth region where f the friction factor is independent of surface roughness.

Using the regression analysis, air change rates were calculated, for a temperature difference of 10 degrees and three different wind speeds. It can be seen that there is a trend for flow to increase with wind speed for straight stack systems (2,4,6) and to decrease with wind speed for bent stack systems (1,3,5), see Figure 10. This is thought to be a function of the design and position of the ridge terminal used for these tests and is nothing to do with the bends as such. Further investigation is in hand which may verify this. It should be noted that the room used was a fairly large kitchen diner and the air change rates achieved were somewhat lower than would have been obtained in a smaller room.

The analysis of these results is not as simple as it might first appear, partly because of the very low Reynolds numbers but also because of the difficulty of calculating wind effects. A full analysis of the results will be the subject of a further paper.

CONCLUSIONS

The performance of six different passive stack ventilator systems has been monitored in a test house. Results indicate that :

- Flow rate measured up the stack was roughly twice as much in the large diameter stack as in the smaller stack for the straight configuration, as would be expected for a smooth duct where entry and exit losses are of the same order as friction losses, and only 50% higher for the stack with bends.

- Including two 45 degree bends in the stack can reduce the flow rate by up to 50%.

- The apparent roughness of the flexible stack material compared with the smooth rigid material, has little or no effect on flow rate, indicating that it is in fact fluid dynamically smooth.

The PSV systems tested appear to work well, providing ventilation for the kitchen under a range of conditions, for typical meteorological conditions of 4 m/s wind speed and temperature difference of 10 deg.C, air change rates of between 0.6 ach and 2.6 ach were obtained. In terms of flow rate this is not as much as is recommended for mechanical ventilation of kitchens but it should be noted that the recommended figures are for intermittent ventilation only and in the case of the passive stack systems they are in use all the time. Another factor is that the hotter the room becomes eg. due to cooking in the kitchen or showering in the bathroom,the higher will be the flow rate at times of most need.

ACKNOWLEDGEMENT

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SYMBOLS USED

ach = air changes per hour
f = friction coefficient (non dimensional)
WD 1 = wind direction 046 - 135 deg.
WD 2 = wind direction 136 - 225 deg.
WD 3 = wind direction 226 - 315 deg.
WD 4 = wind direction 316 - 045 deg.

REFERENCES

1. de Gids,W.F.,and den Ouden,H.P.L.,1974,'Three investigations of the behaviour of ducts for natural ventilation, in which an examination is made of the influence of location and height of the outlet, of the built-up nature of the surroundings and of the form of the outlet'.In Klimaat ventilatie verwarming in woninggen en gebouwen.Delft,Holland,IG-TNO.(In Dutch)

2. Johnson,K.A.,and Pitts,G.,1982,'Experiments with a passive ventilation system',Proceedings 3rd AIC Conference,London.

3. Johnson,K.A.,Gaze,A.I.,and Brown,D.M.,1985,'A passive ventilation system under trial in U.K. homes',Proceedings 6th AIC Conference,Netherlands.

4. Edwards,R.E.,and Irwin,C.,1988,'Further studies of passive ventilation systems - Assessment of design and performance criteria',Proceedings 9th AIVC Conference,Gent,Belgium.

5. Stephen,R.K.,and Uglow,C.E.,1989,'Passive stack ventilation in dwellings', Building Research Establishment Information Paper,IP 21/89.

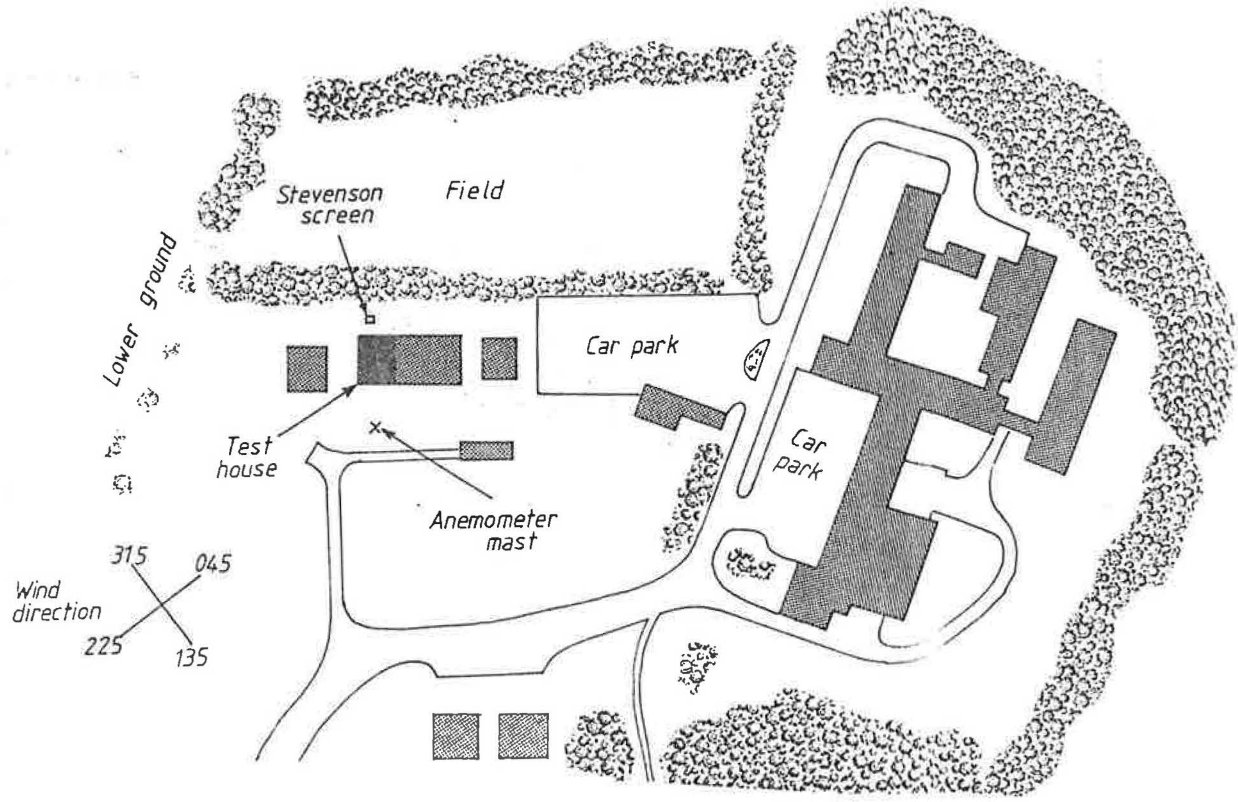

Figure 1 - Test house and surrounding area

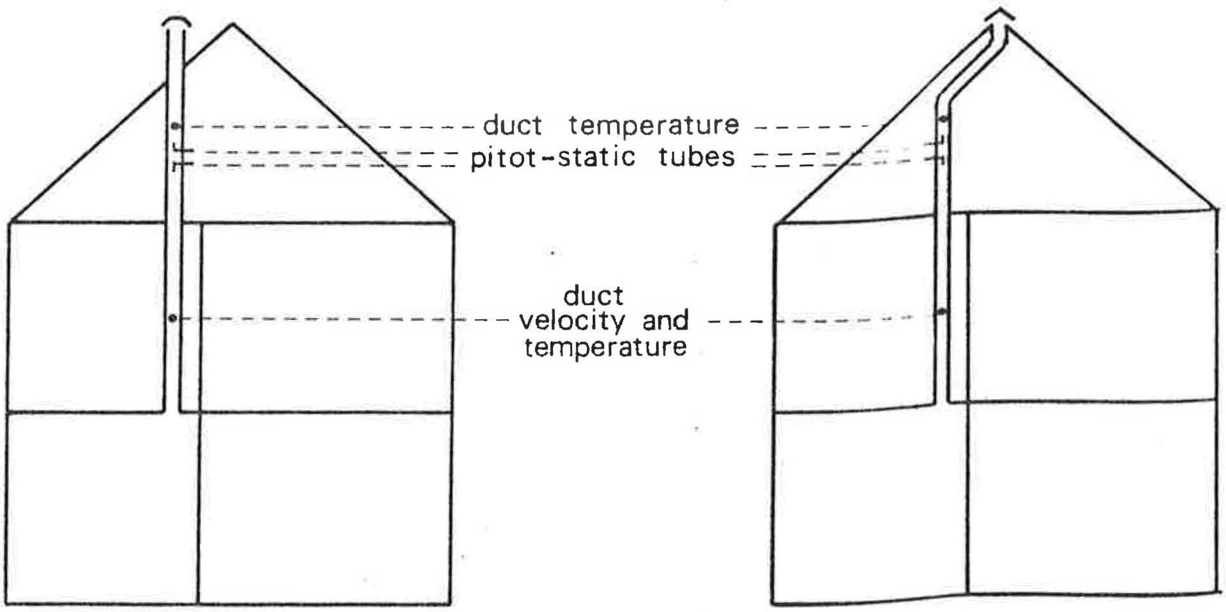

Figure 2 - Stack configurations and instrumentation

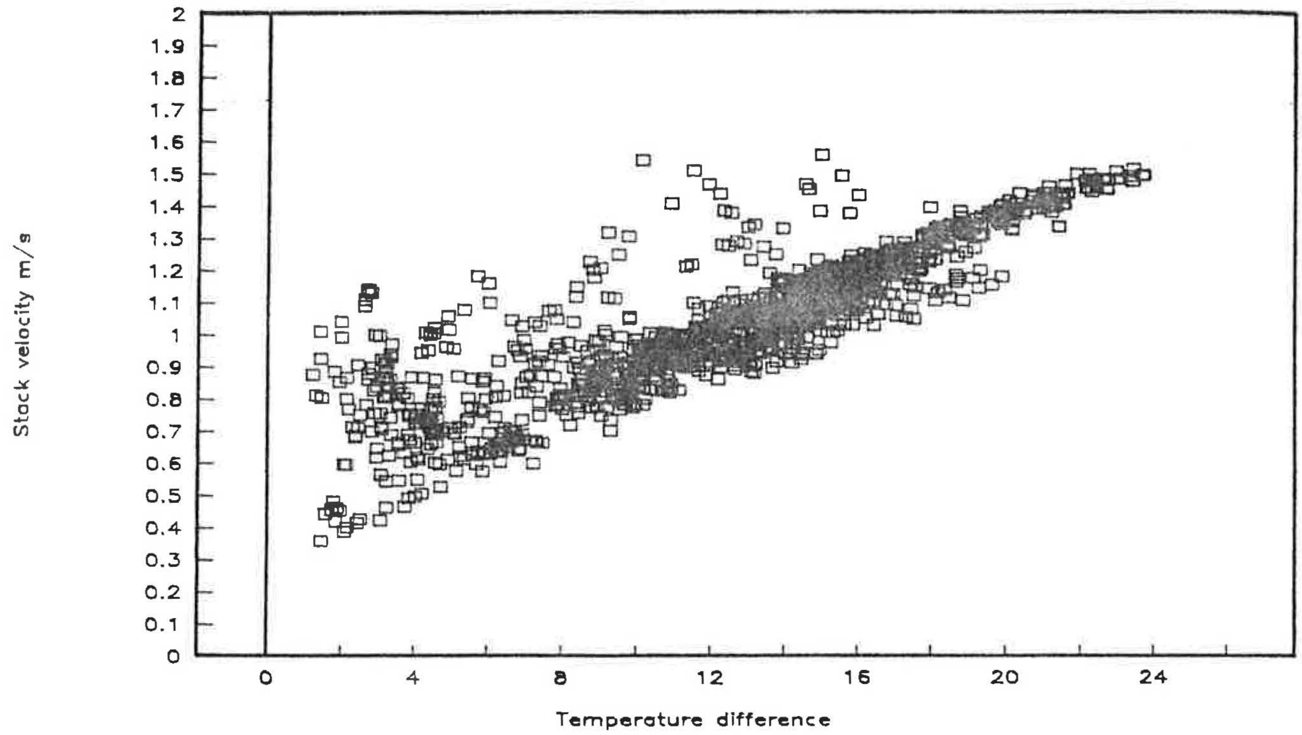

Figure 3a - Initial results (System 5)

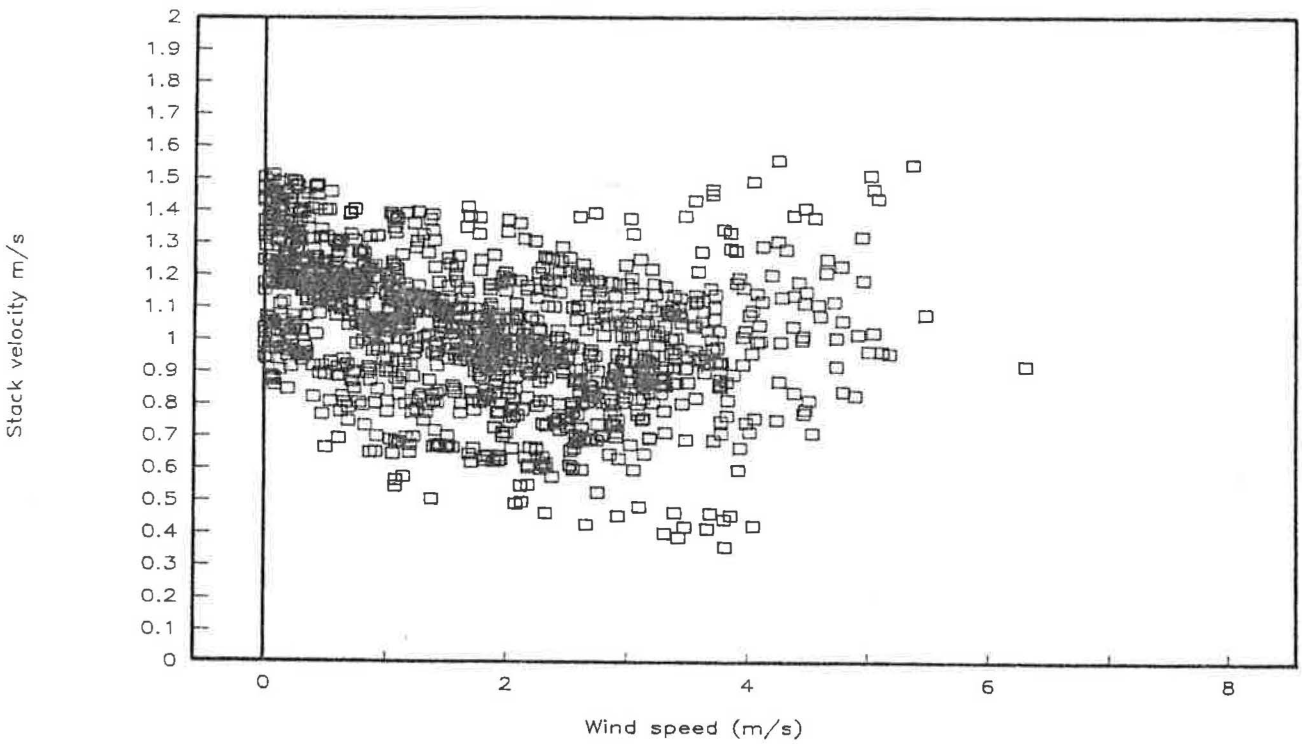

Figure 3b - Initial results (System 5)

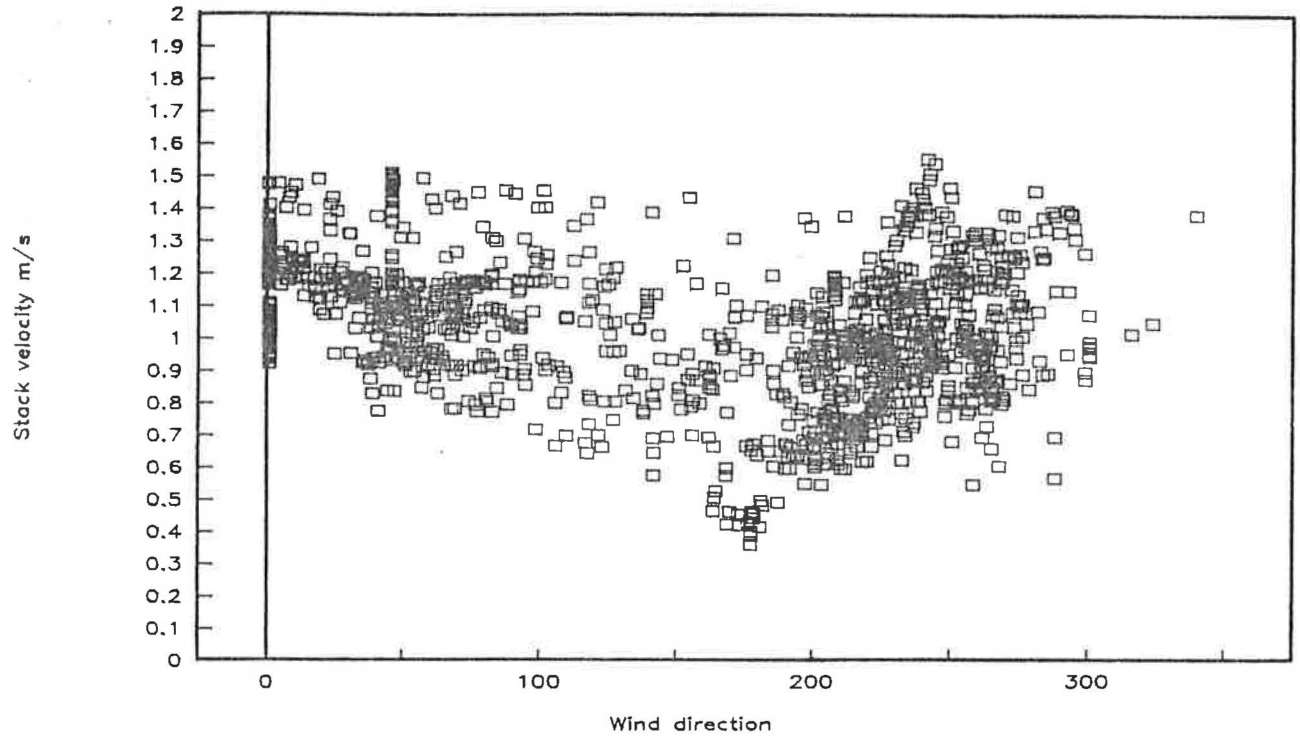

Figure 3c - Initial results (System 5)

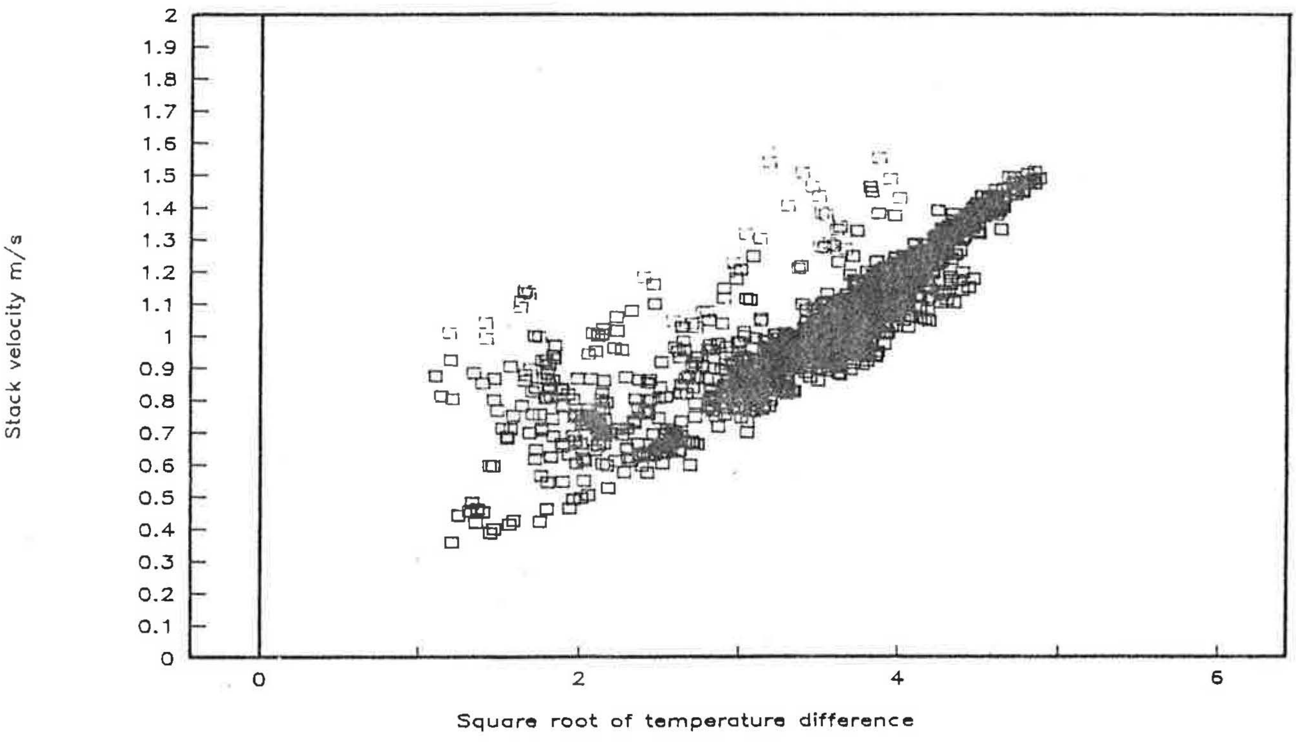

Figure 4 - Stack velocity vs. Square root temp. difference (System 5)

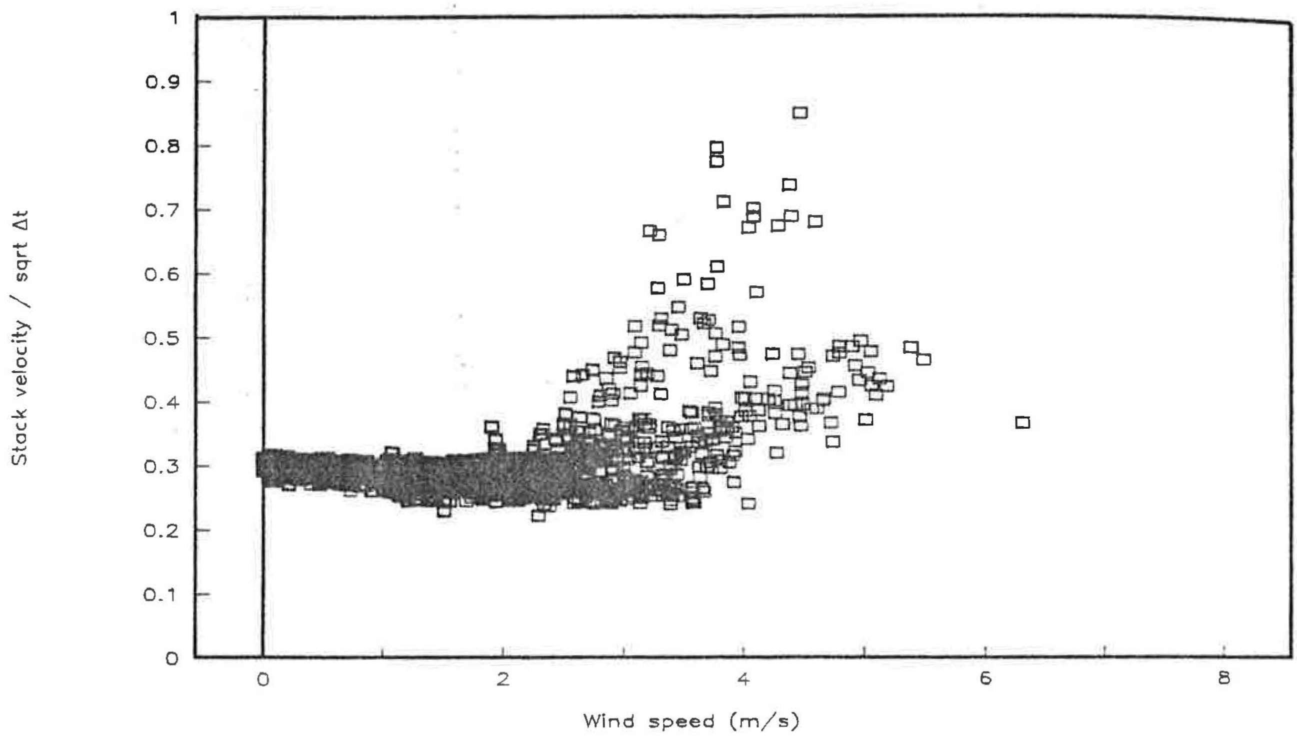

Figure 5 - Effect of wind speed (System 5)

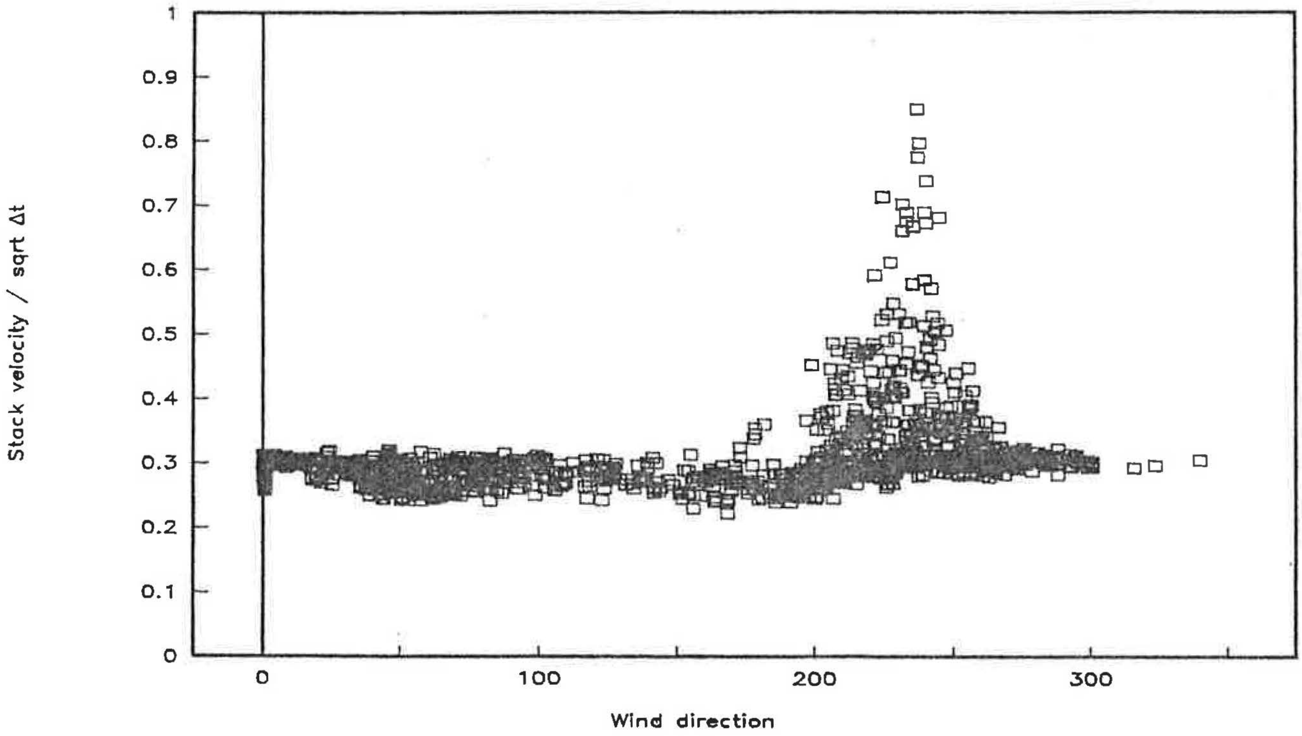

Figure 6 - Effect of wind direction (System 5)

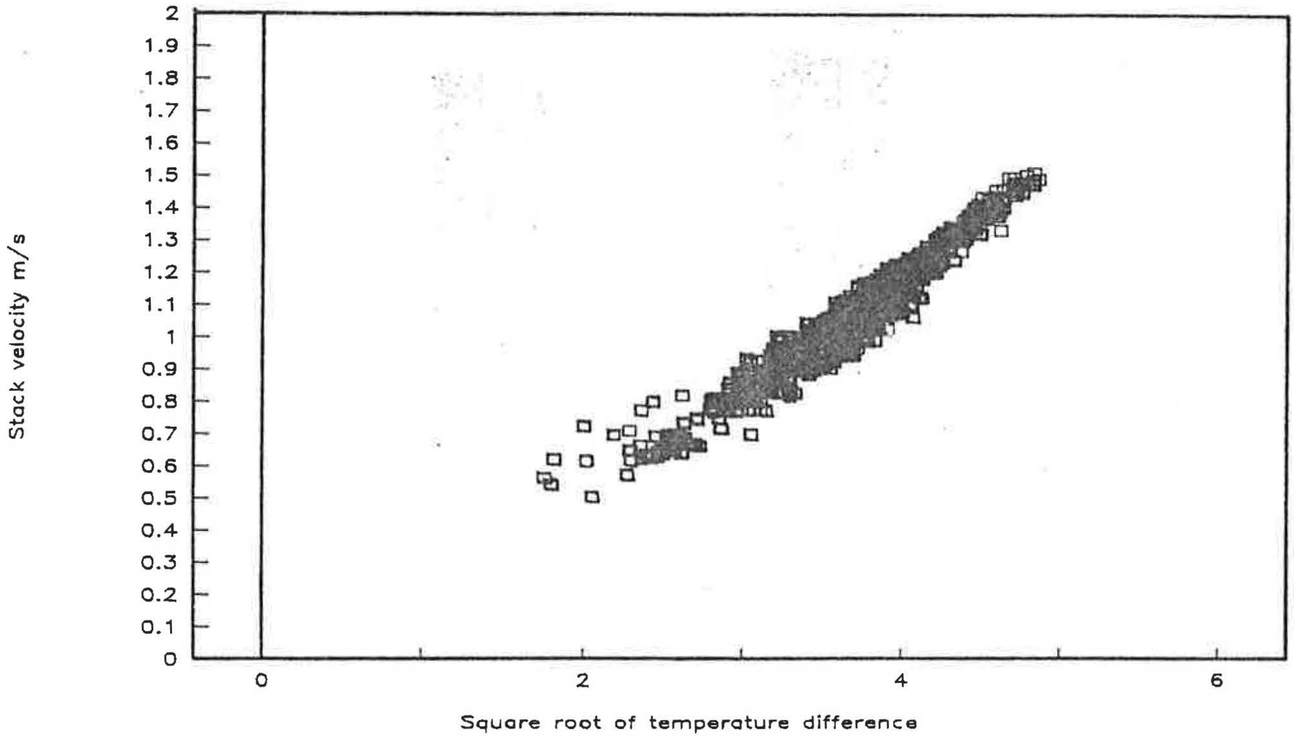

Figure 7 - Effect of temperature difference at low wind speeds (System 5)

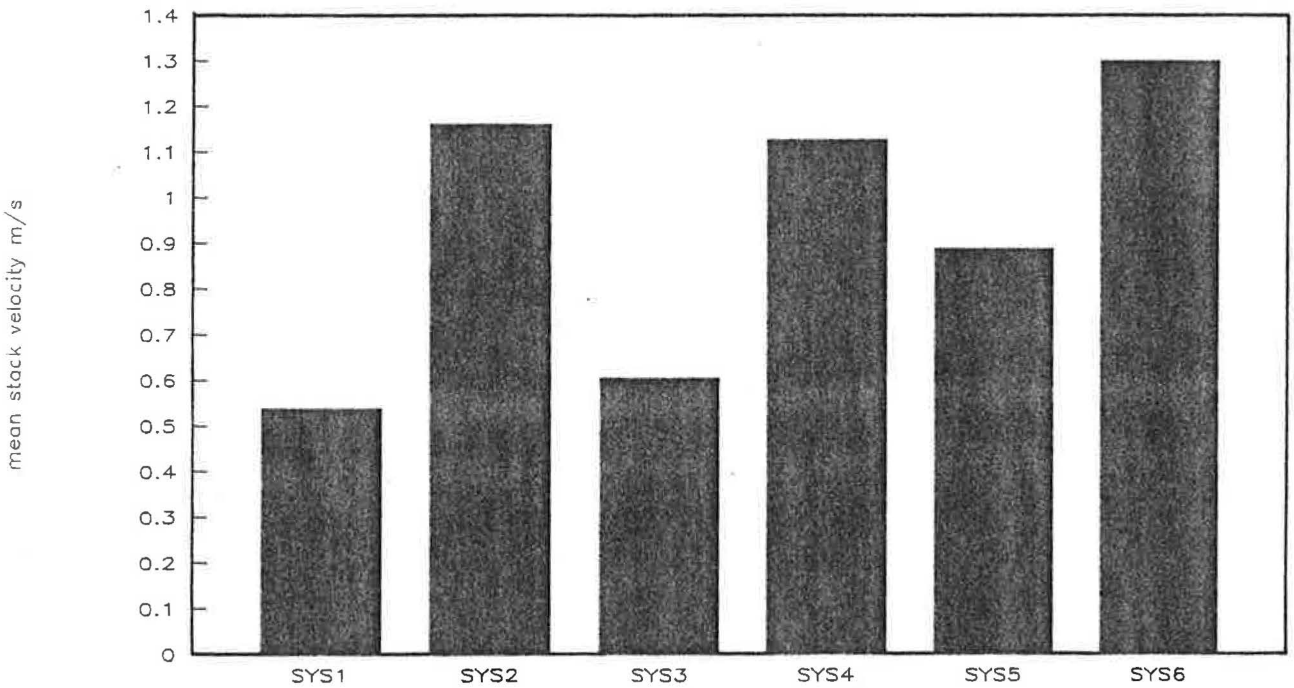

Figure 8 - Comparison of stack velocities

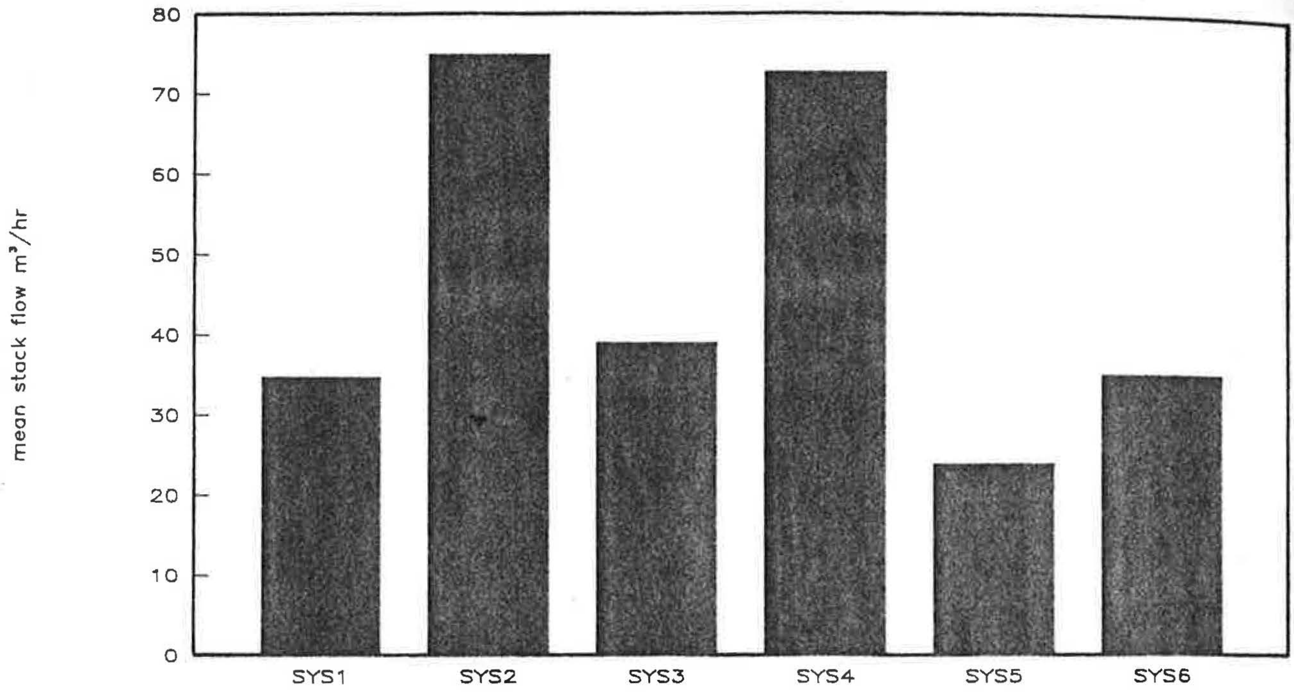

Figure 9 - Comparison of stack flows

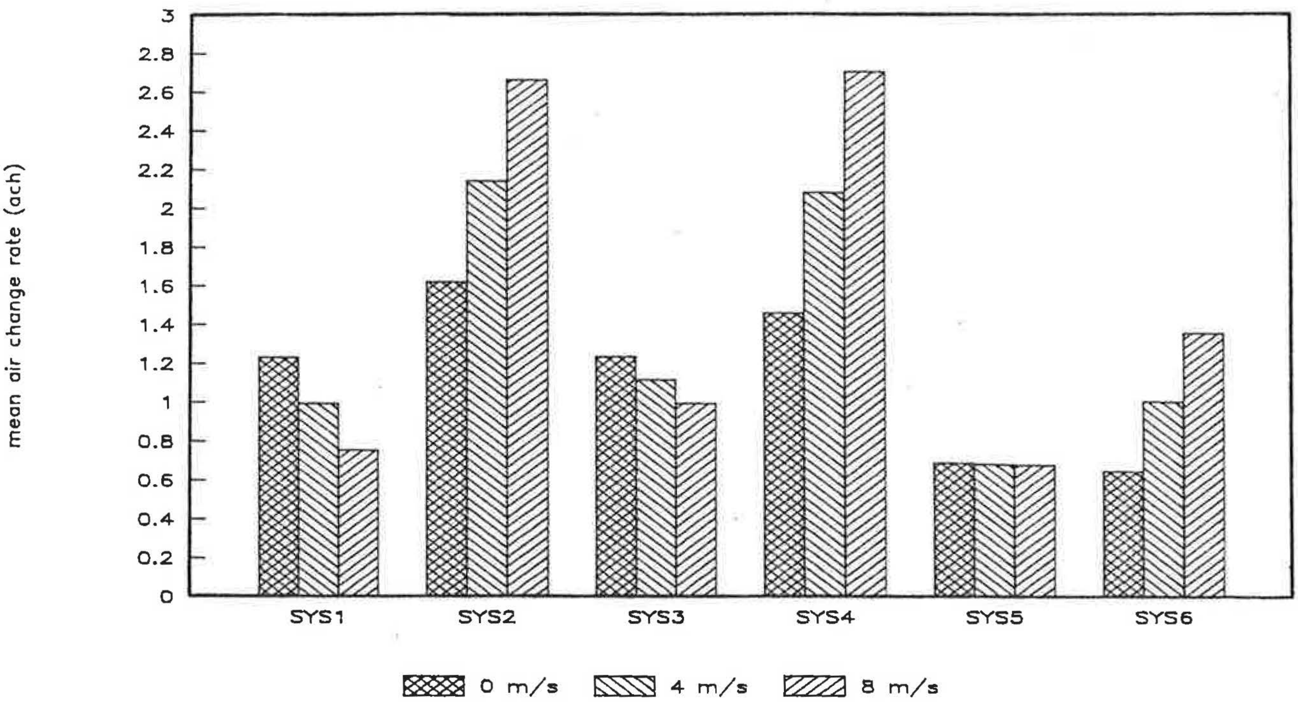

Figure 10 - Comparison of air change rates for different wind speeds