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A Study of Various Passive Stack Ventilation Systems in a Test House

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A STUDY OF VARIOUS PASSIVE STACK VENTILATION SYSTEMS IN A TEST HOUSE.

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SYNOPSIS

The Building Research Establishment has set up various passive stack ventilation systems (PSV) in a test house in order to assess their performance. The test house used was a two storey, end terrace dwelling on the BRE site at Garston.

A PSV was installed in the kitchen of the test dwelling. The duct material, diameter and configuration were varied to determine any differences that they would make to the air flow rates obtained in the duct. In addition, three different ridge terminals were tested and three ceiling inlets.

Air flow rates and temperature in the duct were recorded, together with internal and external temperatures and wind speed and direction. Each system was monitored over several weeks to obtain a spread of climatic data.

Comparisons have been made of the results obtained from each system. Regression analysis has been carried out and predictions of flow rate up the stack, for a typical temperature difference and wind speed, are given for each PSV system.

1. 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 conserving housing, with no open chimneys or flues, can lead to condensation and indoor air quality problems. Moisture can be removed by mechanical extract fans, but another possible solution could be the use of passive stack ventilation systems (PSV). These are vertical, or near vertical , ducts which run from the moisture producing rooms i.e.. kitchens and bathrooms, to the roof of the dwelling. In this way use is 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 noise in operation, little maintenance, no direct running costs, no moving parts to break down and, if installed when the dwelling is built, cheapness of installation.
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, some of which have been described in an earlier report(1). This paper describes the performances of all 15 systems.

2. Description of test house and ventilator systems

2.1 Test house

The house used to test the 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. The room in which the systems were installed is the kitchen/diner, having a volume of 35 m^3. Figure 1 shows the layout of the test house together with the instrumentation positions, table 1 lists the different systems tested.

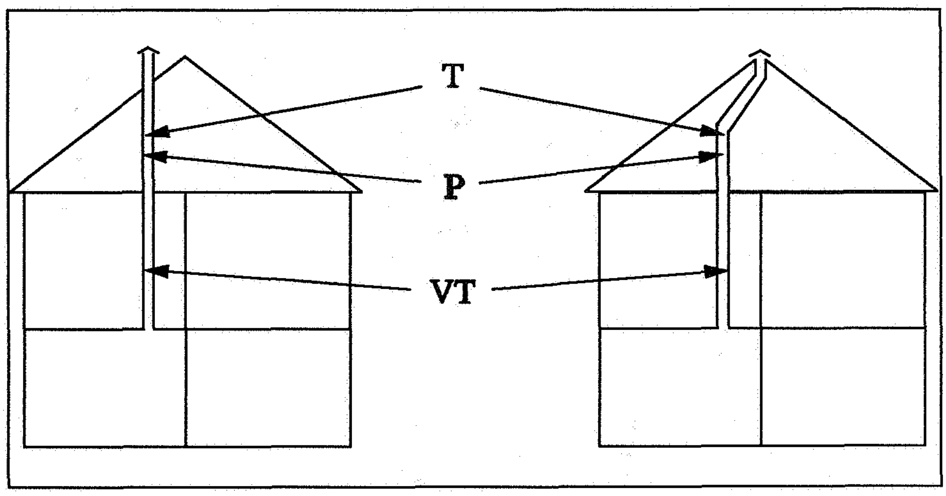

Figure 1: PSV configurations and instrumentation

2.2 Configuration

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 an offset in the attic section to enable the duct to be connected to a ridge terminal see Figure 1.

2.3 Stack diameter and material

Two stack diameters were used, 155 mm and 100 mm, and two different materials, smooth rigid plastic and flexible plastic on a wire spiral. The stack in each case was lagged with fibreglass quilting where it passed through the attic to reduce heat losses and possible condensation problems within the stack.

For two of the systems the stack was cut off at bedroom ceiling height to simulate the shorter stack which would be found in an upstairs bathroom. The same stack was used, rather than monitoring a separate one in the bathroom, to obtain a direct comparison with the longer length stack.

2.4 Terminals

A number of different roof terminals and ceiling diffusers were used. On the straight stack systems a metal 'Chinese hat' shaped terminal was used for the large stack size (SS1) and a plastic 'mushroom' shaped terminal for the small sized stack (SS2). Three types of roof ridge ventilator were used for the systems with an offset and are referred to as (RV1), (RV2) and

(RV3). At the lower end of the duct three ceiling inlets were tested (CT1, CT2, CT3), although of similar design to one another the three inlets had different openable areas.

System no.	Diameter m	Length m	Material	Configuration	Roof terminal	Ceiling terminal
1	0.155	6.88	Rigid	Offset	RV1	-
2	0.155	6.88	Rigid	Straight	SS1	-
3	0.155	6.88	Flexible	Offset	RV1	-
4	0.155	6.88	Flexible	Straight	SS1	-
5	0.110	6.88	Rigid	Offset	RV1	-
6	0.110	6.88	Rigid	Straight	SS2	-
7	0.110	6.88	Flexible	Offset	RV1	-
8	0.110	6.88	Flexible	Offset	RV2	-
9	0.110	6.88	Flexible	Straight	SS2	-
10	0.110	6.88	Flexible	Straight	SS2	CT1
11	0.110	6.88	Flexible	Straight	SS2	CT2
12	0.110	6.88	Flexible	Straight	SS2	CT3
13	0.110	6.88	Flexible	Offset	RV3	-
14	0.110	4.30	Flexible	Offset	RV3	-
15	0.110	4.30	Flexible	Straight	SS2	-

Table 1 Variables for each PSV system

3. Data collection

The following parameters were monitored :
Wind speed, wind direction, external temperature, internal temperature (3 positions), duct temperature (2 positions) and 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 1. Duct velocity was measured using a low velocity flow analyzer. 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). Another method of detecting reverse flow was subsequently installed at the lower end of the stack, this consisted of two adjacent inter-linked thermocouples, one just inside the stack and the other just outside the stack at ceiling height. The datalogger was programmed to monitor temperature differences between the two thermocouples. In the event of the stack temperature being one or more degrees C. below the temperature just outside the stack, the temperature difference and time of occurrence was logged. In this way any prolonged downward flow of cool outdoor air which reached the lower end of the stack could be detected.

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. In the cases of Systems 10 and 11 it was not possible to cover all wind directions in a reasonable time so only directions 136°- 225° and 226°- 315° are included. A range of temperature differences between inside and outside the house was achieved by the use of electric panel heaters.

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 total count was logged, to give half hour average wind speeds.

4. Analysis of data

The data from each system was analyzed using a spreadsheet computer program.
Initially, graphs were drawn of the stack velocity against temperature difference and wind speed. The stack velocity appeared to be largely dependent on temperature difference although not directly proportional to it. On examination, it was found that the stack velocity is in fact proportional to the square root of the temperature difference, indicating turbulent flow. 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. At wind speeds below round 2 m/s the wind had very little effect but had an increasing effect at higher wind speeds. The effect of wind direction for each system was determined by sorting the data into four wind direction quadrants: 045°-135°, 136°-225°, 226°-315°, 316°-045° and then plotting stack velocity divided by the square root of the temperature difference against wind speed for each quadrant. These quadrants approximate to 45° either side of directly onto the four elevations of the test house.

In order to compare the various systems the velocities were converted to flow rates in m^3/h, regressions were then calculated of stack flow with wind speed and square root of temperature difference. From the regressions, predicted flows were calculated for each system for typical conditions of temperature difference of 10°C and wind speed of 4 m/s. Figure 2 shows the results of these calculations.

5. Results

5.1 Effect of configuration and material

5.1.1 Large diameter (systems 1 - 4)

The flows obtained with the straight configurations (2,4) are much higher than those with an offset (1,3), this difference is greater at higher wind speeds. At 4 m/s wind speed and a temperature difference of 10° C the flow rates for the straight stacks are approximately double that for the offset stacks. At wind speeds less than 2 m/s and the same temperature difference the straight stack flow is around 50% higher than the offset stack flow. Material appears to have little effect on stack flow for the offset configurations and although the straight stack systems with flexible ducting produced slightly lower flows at high temperature differences, at a difference of 10°C the flows were very similar.

5.1.2 Small diameter (systems 5 - 7 + 9)
The small diameter stacks showed less variation due to configuration (5+6, 7+9) than the large ones and again material appeared to have very little effect.

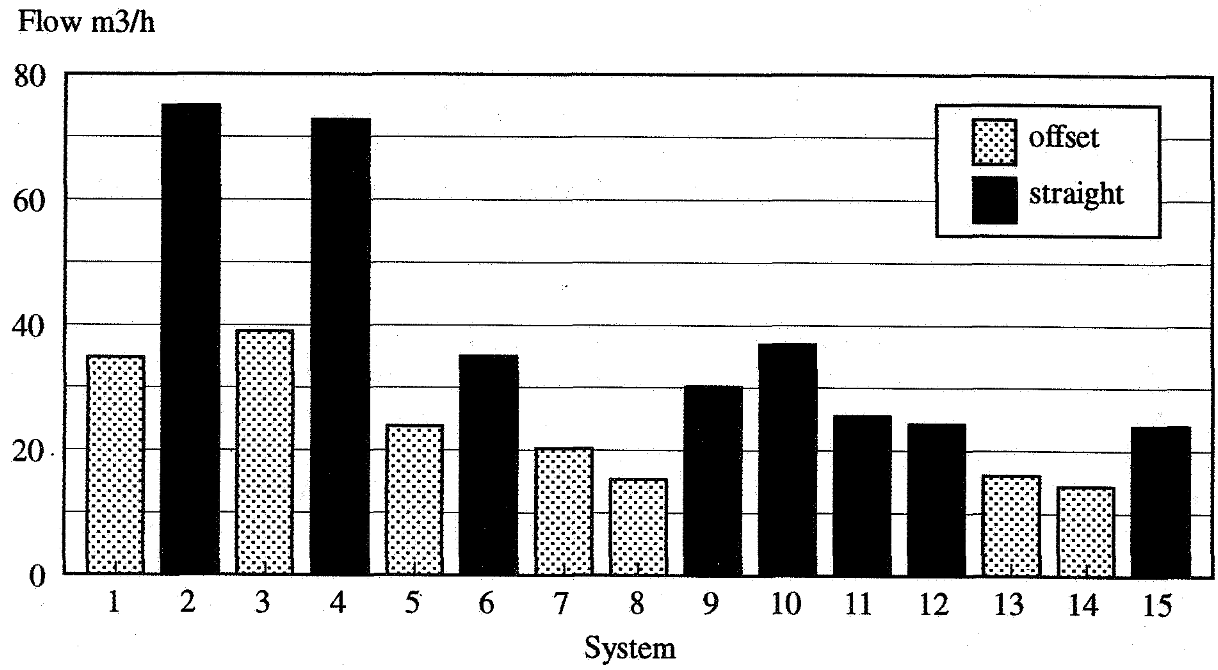

Figure 2: Predicted flow rates for typical conditions
(wind speed = 4 m/s, temperature difference = 10°C)

5.2 Diameter

The flow rates in the larger stacks are, as would be expected, greater than those for the smaller diameter stacks, although the velocities measured are slightly lower. It was thought that this could be due, in part, to the resistance of the room itself, the kitchen door being closed for all tests. Computer modelling of the flows involved carried out by Cripps[2] has shown that this is partly the explanation of the lower velocities in the larger stack ducts. In the case of the straight stacks, the flow rates are roughly proportional to the cross sectional areas of the stacks. For the offset stacks the flows are relatively lower in the larger diameter system, this is probably due to the restricting influence of the ridge terminal. This could also account for the greater difference between straight and offset configurations for the larger diameter systems.

5.3 Length

To find out how much the flow rate would be affected by a different duct length the duct was shortened for systems 14 and 15, being cut off at ceiling height in the bedroom above the kitchen. By comparing the results obtained from systems 13 and 14 it can be seen that there is very little reduction in flow due to a shorter stack length in the offset configuration systems. There is, however, a reduction in flow in the straight system when shortened (9,15).

This difference may be due to the fact that a different room is being ventilated when the duct is shortened and may have different air leakage characteristics from those of the kitchen.

5.4 Terminals

5.4.1 Ridge terminals (7,8,13)
There were variations in flow rates obtained for the three different terminals tested. At low temperature differences there was very little variation in performance but as the temperature difference increased the difference in flow rates between these systems became greater, typically 8.5 m^3 /h at Dt = 20° C.

5.4.2 Ceiling inlets (10,11,12)
The ceiling inlets showed a similar spread of flow rates to the roof terminals ie. little difference at low temperature differences, and 10 m^3/hr. at Dt = 20° C.

The diversity of flow rates obtained with both the ridge terminals and the ceiling inlets is due to the difference in free area and the resistance to flow of each design. These results show the importance of choosing or specifying terminals which do not restrict the air flow: ideally the free area of the terminal should not be less than that of the duct itself. This explains why the differences between the flows in the straight and offset systems was greater with the large diameter ducts than with the small diameter, the same terminals being used for both diameters. In the case of the large duct the ridge terminals were restricting the flow and if a terminal with a larger free area had been used the flows would almost certainly have been greater. This explanation has been reinforced by Cripps[2] with computer simulation of the flows involved.

Wind tunnel tests have been carried out by Welsh[3] on a range of terminals, both for ridge installations and those ducts which pass through the roof slope, this work identifies the terminals most suitable for passive stack ventilation systems.

6 Reverse flow

It was stated earlier that no prolonged periods of reverse flow were detected using the upward facing pitot static tube The alternative method, that of using two thermocouples, did, however, indicate that under certain conditions, reverse flow could occur. This method was not installed until midway through the system 8 testing period so only systems 8 to 15 can be discussed here.
A datalogger was programmed to monitor the temperatures of the two thermocouples once every 5 seconds, in the event of the duct air temperature being one or more degrees lower than near the ceiling just beside the duct, signifying that cooler air was flowing down the duct into the room, the logger would record the time of occurrence and the temperature difference. Subsequently, a note was made of each half hour period when reverse flow had occurred, together with the number of minutes during each half hour in which there had been reverse flow.

System 14 (short offset flexible stack with no ceiling diffuser) showed the greatest amount of reverse flow, with some also indicated for systems 8,11 and 15. Figure 3 shows the distribution of half hour periods containing some reverse flow by wind direction for system

14, it can be seen that this reversal occurs around two particular wind directions and is probably caused by the effects of adjacent trees. The amount of reverse flow in each half hour period, where some occurred, varied between 1 and 50%.

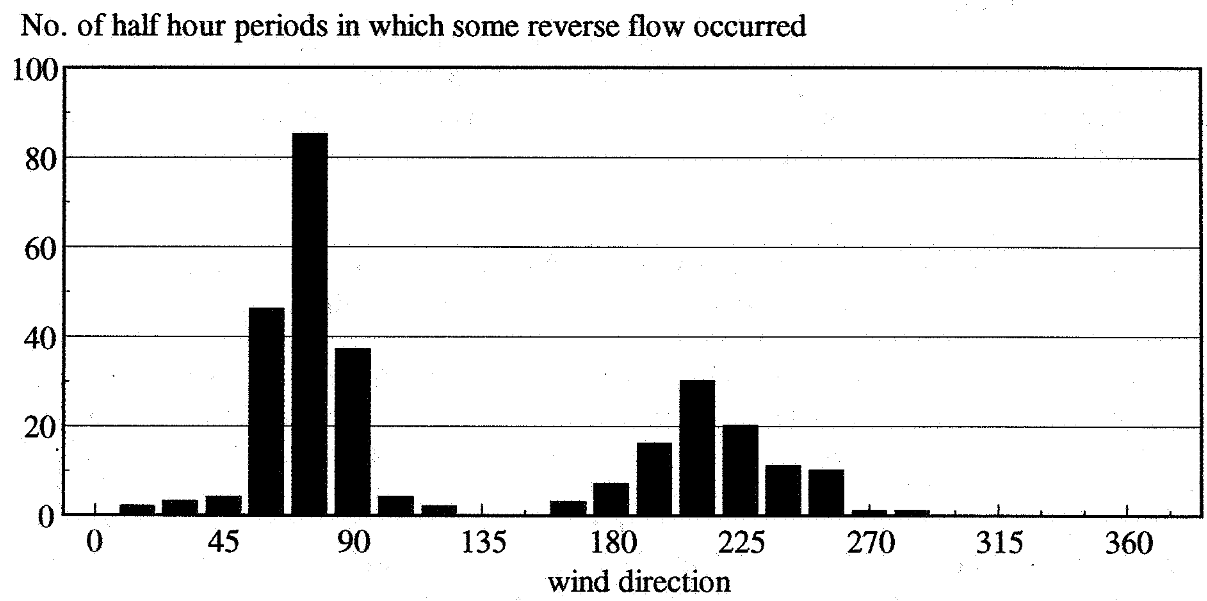

Figure 3: Indications of reverse flow in system 14

The total time during which reverse flow occurred for systems 8 to 15 was 0.7% and for system 14 alone 2.7%.

Reverse flow has only been recorded if it reached the lower end of the stack so the increase noticed in system 14 is probably due to the shorter length of stack, the same system with a longer length stack (System 13) showed no indication of reversal. It is possible that air sometimes flows down the duct for brief periods not long enough to reach the room below, such reversal would not be a nuisance in terms of occupant discomfort although it would reduce the overall flow rate .

7 Discussion

The performance of fifteen different passive stack ventilator systems, using different materials, configuration, diameter, length and terminals, has been monitored in a test house over a range of climatic conditions.

For typical meteorological conditions of 4 m/s wind speed and temperature difference of 10° C, flow rates of 14 - 75 m^3/h were obtained. Thus appropriately sized passive stack ventilation systems could provide adequate ventilation for most kitchens or bathrooms over a 24 h period. Further work carried out by Shepherd et al[5] has shown that over a 24 h period, the air change rate using a PSV system was approximately the same as using an extract fan for 2 h during that period.

An advantage that PSV systems have is that because flow rate increases with temperature difference, the systems become most effective when the greatest flow is required ie. when cooking is taking place in the kitchen or showering/bathing in the bathroom.

8 Conclusions

Results indicate that :

1) 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 and 50% higher for the stack with an offset.

2) Increasing the diameter of the stack does not necessarily increase the flow rate proportionally, due to the possible restriction of flow by the roof terminal and the resistance caused by the air leakage characteristics of the room.

3) For a given duct diameter, including an offset in the stack can reduce the flow rate by up to 50% depending on type of ridge terminal used.

4) The roughness of the flexible stack material compared with the smooth rigid material, has little or no effect on flow rate.

5) The terminal specified for each end of the duct should have a free area of not less than that of the duct itself.

6) There is an increased risk of reverse flow reaching the room in the case of upstairs bathrooms due to the shorter length of stack involved.

7) There should be sufficient provision for air to enter the room, by means of trickle ventilators or similar, so that the room itself does not act as a restriction to flow.

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