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Case Studies of Passive Stack Ventilation Systems in Occupied Dwellings

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CASE STUDIES OF PASSIVE STACK VENTILATION SYSTEMS IN OCCUPIED DWELLINGS.

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SYNOPSIS

A possible alternative to mechanical extract ventilation for kitchens and bathrooms is passive stack ventilation (PSV). BRE has carried out work on this type of system in a test house under controlled conditions. To find out how well they worked in practice, four occupied dwellings were monitored over a period of 2 - 3 weeks each. Each dwelling had two ventilation ducts.

Air flow rates within the ventilation ducts were measured, together with humidities, temperatures and climatological data.

The results show that the risk of problems due to condensation can be reduced by the use of this type of ventilation system.

The systems were found to have been poorly installed and where possible the faults were corrected as part of the study. Nevertheless the systems successfully kept down moisture levels below 70% RH for all but a small proportion of the time. The design and performance of the systems is discussed and advice given on how these could be improved.

This study demonstrates the need for clear and simple guidance on PSV systems to enable them to work to maximum efficiency.

1. Introduction

BRE has carried out a programme of work in a test house on the BRE site to monitor the performance of various Passive Stack Ventilation systems (PSV) under controlled conditions[1]. To determine how well this type of system performs under normal occupied conditions, four Local Authority dwellings in North London were monitored during the heating season. Each dwelling was monitored for a period of approximately 3 weeks.

The objectives of the study were:

1) To measure the flow rates obtained in the stack ducts and relate these to the humidity within the dwelling.

2) Determine whether the PSV systems would keep the relative humidity at sufficiently low levels to minimise the risk of condensation.

3) Assess the design and installation of each system and give advice on possible improvements.

2. Description of dwellings and PSV systems.

2.1 Dwellings

The four dwellings which were monitored were all 2-storey, end-terraced maisonettes above flats, thus occupying the second and third storeys of 3-storey blocks. The dwellings were built in the mid 1970s, originally with flat roofs and wooden-framed, single-glazed windows. They were refurbished approximately 2 years before testing, with the addition of pitched roofs, double glazed windows and PSV systems for the kitchen and bathroom. The position of the PSV serving the kitchen is somewhat unusual in that it is situated on the landing at the head of the stairs, the kitchen being at the foot of the stairs. In 2 of the dwellings (C and D) the kitchen was open plan with the hall and in the other 2 it was separated from the hall by a door.

2.2 PSV systems

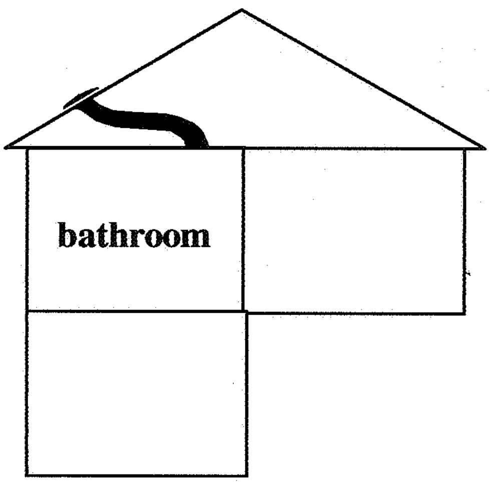

Figure 1: Design of bathroom PSV

The ducting used for the PSV systems was an insulated, flexible type, with 155 mm diameter used for the landing and 100 mm diameter for the bathroom. The landing duct terminated at a ridge ventilator whilst the bathroom one had been designed to terminate at a tile vent, situated low down on the roof, which was little higher than the bathroom ceiling (figure 1). The ceiling outlets were of the circular "valve" type with a central adjusting section to regulate air flow. On most of the systems tested these inlets were initially fairly tightly shut, thus restricting the air flow, most probably because this is the way they had been delivered from the manufacturer and had not been opened properly when fitted.

On inspection, the PSV systems were found to be badly installed with tight bends, much excess ducting and no supporting framework. In the first dwelling the landing duct had, in fact, become detached from the ridge ventilator and was lying on the floor of the loft. The bathroom ducts were of very poor design, having little difference in height between the ceiling outlets and the tile vent terminals on the roof slope.

3. Monitoring programme.

In view of the poor installation of the PSV systems, it was decided to monitor them for a period of time 'as found' then improve them as much as possible by taking out excess ducting, straightening bends and opening up ceiling outlets. Monitoring would then be carried out over a further period to determine the effects of the modifications. In this way some measure of how a systems' performance could be affected by bad design and/or workmanship could be assessed. It should be said that even in the improved state these systems would fall well short of current guidance given by BRE[(2)]. In the case of the first dwelling, where the ducting had become detached, no 'as found' condition was tested. Table 1 shows the different conditions monitored for each dwelling.

Dwelling	Condition 1	Condition 2	Condition 3
A	As found *	Vents opened fully	-
B	As found	Ducts shortened	Vents opened fully
C	As found	Vents opened fully, ducts shortened	-
D	As found	Ducts shortened	Vents opened fully

** Landing system was disconnected when found, this was reconnected before monitoring commenced.*

Table 1: Monitoring conditions in test dwellings

When monitoring had been completed, the air leakage of the dwelling was measured using the 'Fan pressurisation ' technique as described by Stephen [3]. In brief, the air leakage is measured by sealing a fan into an external doorway and measuring the pressure difference between inside and outside simultaneously with the air flow through the fan. This procedure is repeated for several different pressure differences. The air leakage can then be calculated and is given as the air change rate obtained at an applied pressure difference of 50 Pa.

4. Monitoring equipment.

Each duct had equipment installed to measure :

air flow velocity,
humidity at inlet,
temperature at the top end.

In addition, temperatures were measured in the bathroom and landing immediately below each stack. Local wind speed and direction, and external temperature were measured at a mast attached to the gable end of the block approximately 2m above the eaves. This location was less than ideal so wind data was also obtained from the London Weather Centre, which is the nearest meteorological station to the test site.

All instruments were scanned once every 10 seconds and half-hourly averages recorded on 'Squirrel' data-loggers.

5. Results

5.1 Increases in flow rates after modifications

The data sets obtained during each monitoring period were analyzed in the same way as the previous sets from the BRE test house[1]. The air flow rates monitored in the landing stack of dwelling C were not used in the analysis as, due to instrument malfunction, they were not considered sufficiently reliable.

Regression analysis was carried out of duct air flow rate with the square root of the temperature difference and wind speed. From the results of this analysis curves were drawn of stack flow versus temperature difference up to 20° C for a typical wind speed of 4 m/s. Figure 2 shows the results obtained from dwelling A, which are typical of the increase in flows achieved in three of the four dwellings. In each plot the lower line is the 'as found' condition and the higher one, after modifications.

In dwellings A, B and C the flow increased considerably after modifications had been made to the systems. There were, however, no significant increases in the flow rates measured in dwelling D, possibly because there was very little excess ducting to remove and the ventilators were opened fairly well in the 'as found' condition.

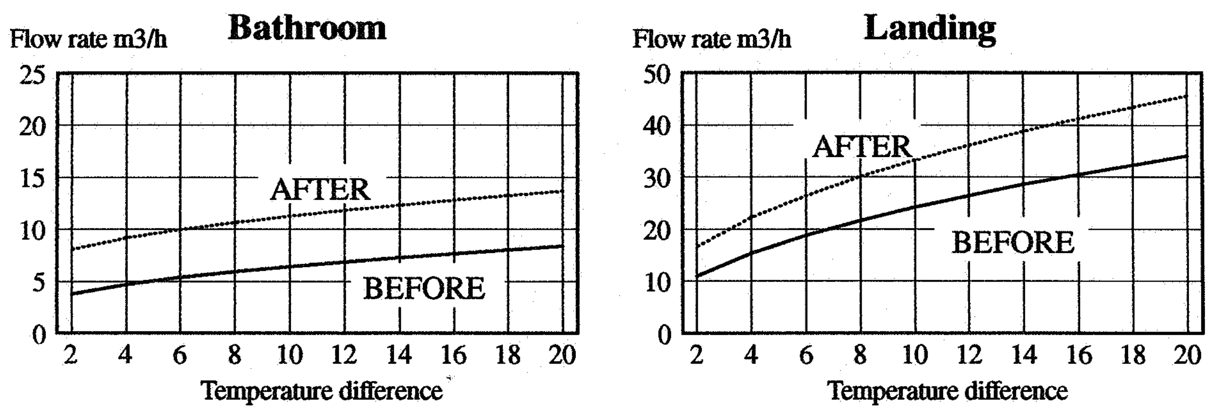

Figure 2: Typical increase in duct flow rates after modifications to PSV systems.

5.2 Moisture removal

To determine how well the PSV systems coped with moisture removal, cumulative frequency histograms were drawn of humidity levels in bands of 10% RH and the percentage of time that each level was exceeded. Figure 3 shows the results in the bathroom and landing of dwelling A after modifications. In the case of the bathroom, the humidity was always above 50% and the landing, 40%. The height of the 70% bar indicates the proportion of the time that the relative humidity is above 70%. In dwelling A 70% was exceeded 10% of the time in the bathroom and 0% on the landing. Table 2 gives the percentages for all four dwellings. If 70% RH is exceeded for lengthy periods then mould growth may occur[4]. In dwellings A,B and C the humidity levels measured are unlikely to give rise to problems of mould growth. In dwelling D, the percentage of time when 70% RH was exceeded is slightly higher in the 'as found' condition (24% of time in the bathroom) and there was indeed some evidence of mould growth. This was, however, a dwelling which was inadequately heated and where wet washing was hung indoors, not only in the bathroom but also in the kitchen, hall and landing areas. The decrease in RH above 70% shown in table 2 for this dwelling is not attributable to any modifications carried out as the was no increase in flow rates, as stated earlier. The internal temperatures, however, were higher during the measurements made after modifications thereby reducing the RH levels. It is probable that with the internal temperature maintained at the higher level, the mould growth found in this dwelling would not increase.

The design of the system was, however, still well below the standard of the new guidance.

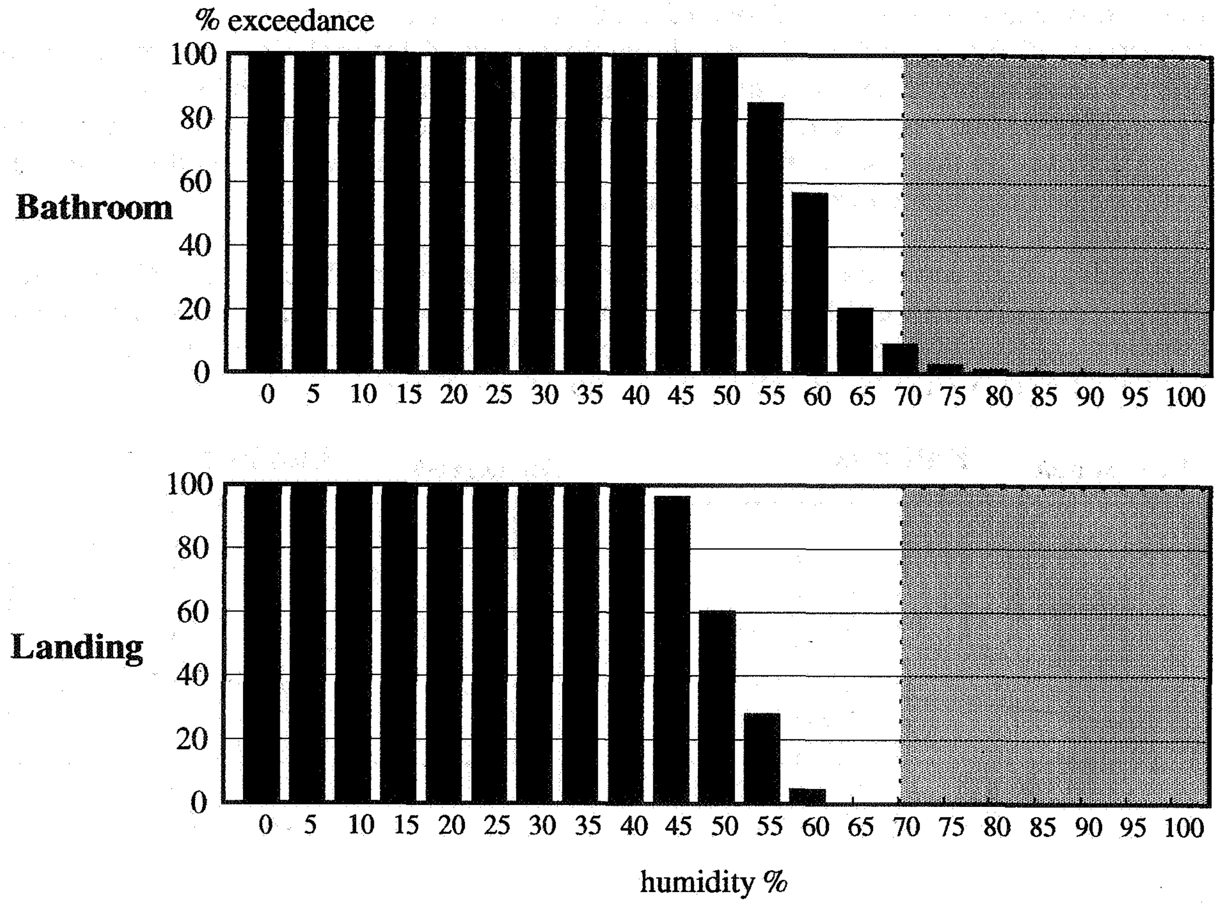

Figure 3: Cumulative frequency histograms for dwelling A

Dwelling	Bathroom		Landing	
	Before mods.	After mods.	Before mods.	After mods.
A	16.6%	9.3%	0.9%	0%
B	2.7%	2.1%	0%	0.2%
C	0.6%	0%	0.9%	0.7%
D	24.0%	8.5%	7.9%	0.1%

Table 2: Percentage of time RH greater than 70%

6. Air leakage measurements

Table 3 gives the results of the air leakage tests carried out in each dwelling with passive stack vents open, and shows that they lie within the range 10 - 12 air changes at 50 Pa. Analysis, by BRE, of a sample of U.K. dwellings show that the median air leakage at 50 Pa is in the order of 14 air changes per hour[5], the dwellings used in this study are, therefore, more airtight than average.

BS 5250[4] recommends ventilation rates of between 0.5 and 1.5 air changes per hour for the control of condensation. By applying the 1/20 rule (natural ventilation rates are approximately 1/20 of the air leakage rate measured at 50 Pa), to the air leakage rates of the test dwellings, it can be seen that they equate to natural ventilation rates of just over 0.5 ach. The dwellings should, therefore, have sufficient ventilation for control of condensation.

Dwelling	air changes per hour (+ve pressure)	air changes per hour (-ve pressure)	air changes per hour (mean)
A	11.5	10.8	11.2
B	12.1	11.7	11.9
C	11.2	10.5	11.9
D	10.4	9.8	10.1

Table 3: Results of air leakage measurements with passive stack vents open

7.Reverse flow

In certain circumstances reverse flow may occur within the PSV systems. This was detected by observing the stack temperatures in relation to the room and external temperatures. In the landing stacks temperatures generally followed the same pattern of variation as the temperature in the room which they served, but occasionally, in house B, dropped towards the external temperature, indicating that cooler air from outside was flowing down the stack. This phenomenon occurred when the wind blew from particular directions and was possibly due to the influence of adjacent buildings. Greater periods of reverse flow were detected in all the bathroom stacks, due to the bad positioning of the roof terminal referred to earlier in section 2. An example of the deviations in temperature pattern can be seen in figure 4,

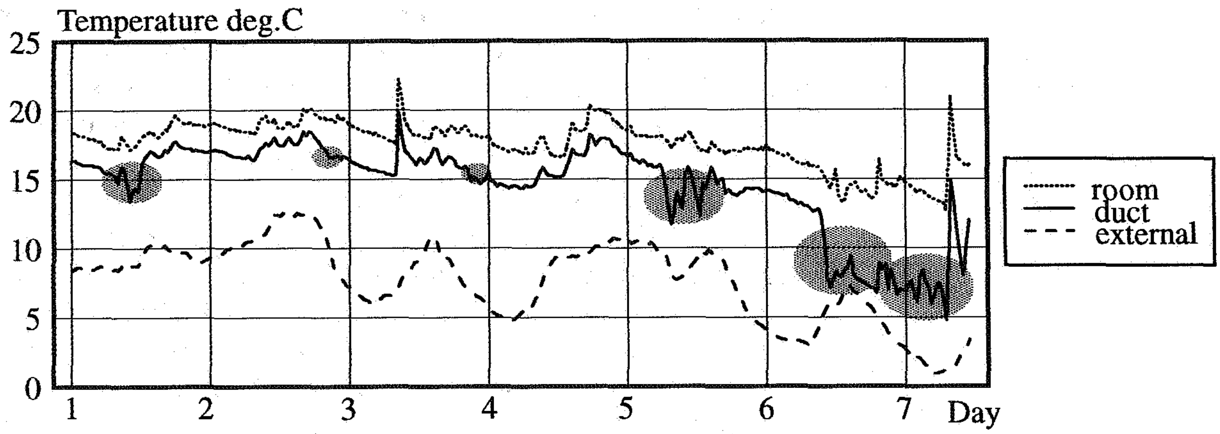

Figure 4: Temperatures in room, duct and outside, showing periods of possible flow reversal

where the top line is the room temperature, the bottom line the external temperature and the centreline, the temperature in the duct. The periods where the duct temperature deviated from the pattern followed by that of the room temperature show when reverse flow was possibly occurring and are indicated by shading.

Even in this extreme case however, flow reversal only occurred a small proportion of the time and was clearly limited in amplitude and had little effect on the average ventilation rate.

8. Discussion

The design of the PSV systems monitored in this study was poor.
The systems serving the kitchen were obviously installed with low cost in mind and would have been more effective if the duct had run from the kitchen. The way in which they were installed i.e.. the outlet from the landing, resulted in air being extracted from other areas of the dwelling as well as the kitchen, so although the flow rates would appear to be adequate it should be remembered that not all the airflow was from the kitchen.

In the case of the bathroom systems, the duct should have been taken straight through the roof and terminated at ridge height to give a greater height difference between inlet and outlet and to avoid flow reversal. This would also have eliminated the right angle bends in the ductwork which reduce the flow rate. An alternative solution could have been to terminate the ducting at the ridge although this would have necessitated using longer lengths of ducting so would have been slightly more expensive. Figure 5 shows the existing design (a) and alternatives (b) and (c), which would reduce the possibility of reverse flow to a minimum.

If we look back at the air leakage results, a whole house infiltration rate in the region of just over 0.5 air changes per hour under normal climatic pressures, is indicated. If we add the flow rates measured in the landing and bathroom stacks of each dwelling, at a temperature difference of 10° C and a wind speed of 4 m/s, an average flow rate of around 45 m^3/h is obtained. This represents a contribution to the whole dwelling ventilation rate of 0.25 air changes per hour. In simple terms this suggests that the PSV systems contribute almost half the total ventilation. However, to determine the interaction between PSV and whole house ventilation it is necessary to use a single cell ventilation model such as BREVENT [(6)].
As previously mentioned, these dwellings are slightly tighter than the UK average, one could thus assume that a significant amount of water vapour is removed, not by excess infiltration through the fabric of the dwelling but by the flow through the PSV ducts.

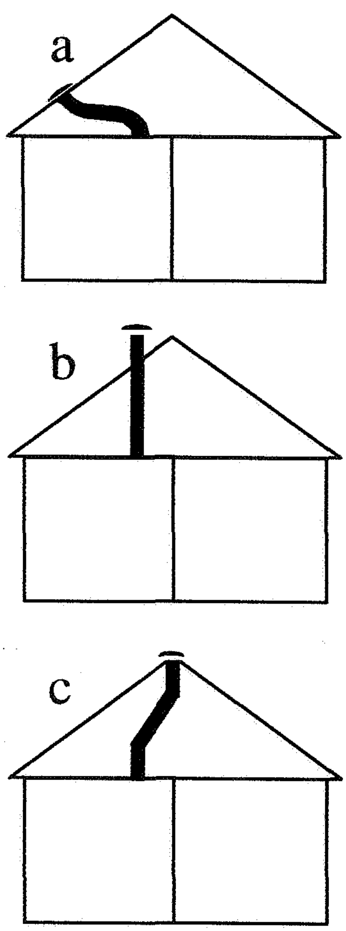

Figure 5: Existing bathroom PSV design and alternatives for improved efficiency.

In the 'as found' condition, moisture was kept to an acceptable level in all but one of the dwellings. This was, as stated earlier, a dwelling where drying of washing indoors seemed to take place for a large proportion of time.

9. Conclusions

1) Four occupied dwellings, with passive stack ventilation systems, were monitored over a period of weeks to determine how well the PSV systems performed.

2) The PSV systems in the bathrooms had been designed so that the ductwork ran parallel to the loft floor and had sharp bends, restricting the airflow.

3) The majority of the PSV systems monitored had been badly installed with much excess ducting, too many bends and no support.

4) The systems gave better airflow performance when excess ducting had been removed and any bends straightened out as much as possible.

5) In spite of poor design and installation the systems coped well with removal of moisture and kept the relative humidity levels below 70% for all but a small percentage of the time.

6) Care should be taken when designing and installing PSV systems to ensure that :
   a) Ductwork is as straight as possible,
   b) stacks terminate at or near the ridge,
   c) tile ventilators are not used as they can cause reverse flow in the system, this may give rise to occupant discomfort and reduced overall flow rates up the duct and
   d) terminals are opened sufficiently so that they do not restrict air flow

7) This study demonstrates the need for clear and simple guidance on passive stack ventilation systems as contained in the Reference 2, but notwithstanding unsatisfactory design and installation these systems performed satisfactorily in terms of keeping down relative humidity below 70%.

References

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