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# The Relative Energy Use of Passive Stack Ventilators and Extract Fans

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# THE RELATIVE ENERGY USE OF PASSIVE STACK VENTILATORS AND EXTRACT FANS

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## SUMMARY

The relative energy use of PSV and extract fans has been a matter of considerable controversy, particularly in the UK. A steady state methodology is presented based on the approach of BS5250 and that of Professor Meyringer (Air Infiltration Review November 85). The ventilation, over and above background ventilation, required to remove moisture is shown to be affected by; the rate of moisture production in the dwelling, the moisture content of the outside air, the air temperature of the dwelling, the air tightness of the dwelling, the moisture absorption of the structure and furniture, the dwelling size, whether trickle vents are open or closed, the proportion of moisture removed in the kitchen or bathroom.

Equations are derived for the energy used by PSV, both uncontrolled and humidity controlled and by humidity controlled extract fans. Manually controlled systems, either fans or PSV, have not been considered because their use depends on human behaviour and there is, as yet, a lack of detailed reliable data. Conditions are determined for one or the other to be the greater. The effect of varying the above variables and opening or closing the kitchen door is investigated. It is shown that PSV both controlled and uncontrolled, has an energy advantage in heavily occupied, cold and small dwellings. In average dwellings there is little difference and extract fans are more energy efficient in large, warm and lightly occupied dwellings.

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## LIST OF SYMBOLS

| | |
|---|---|
| $Q_1$ | Airflow rate required to remove moisture $m^3$/day |
| $\rho_{air}$ | Density of air kg/$m^3$ |
| G | Moisture generation rate kg/day |
| $g_{inside}$ | Moisture content of the inside air kg/kg |
| $g_{outside}$ | Moisture content of the outside air in kg/kg |
| $\alpha$ | Proportion of moisture extracted in kitchen and bathroom by extract fan |
| $B_f$ | Flow reduction factor fan = additional ventilation in dwelling/flow through fan |
| $B_{psv}$ | Flow reduction factor PSV = additional ventilation in dwelling/flow through PSV |
| $Q_2$ | Background ventilation rate $m^3$ /day |
| $Q_3$ | fan flow rate $m^3$/day |
| $g_{70}$ | moisture content of inside air corresponding to 70% RH at the inside air temperature kg/kg |
| $\Delta T$ | temperature difference inside to outside ° C |
| $E_1$ | efficiency of boiler or heating appliance |
| P | fan power watts |
| $E_2$ | efficiency of electricity generation and distribution % |
| $Q_4$ | PSV flow rate $m^3$/day |
| $\gamma$ | proportion of the time for which the fan runs |
| $T_{in}$ | inside temperature °C |
| $T_{out}$ | outside temperature °C |
| RH | relative humidity % |
| $RH_o$ | RH at ref point % |
| $T_o$ | inside temperature at reference point |
| $g_o$ | moisture content of inside air at ref point kg/kg |
| $A_1$ | open area of humidity control device $cm^2$ |
| $A_o$ | open area of humidity control device at $RH_o$ $cm^2$ |
| $A_2$ | area of stack $cm^2$ |
| $k_1$ | loss coefficient of humidity control device |
| $k_2$ | loss coefficient of rest of stack system |

## 1. INTRODUCTION

In the UK the pollutant controlling the ventilation rate is moisture and thus the energy used in ventilation is dependent on the process of moisture transfer and removal. This is a dynamic process operating on a multi cell flow process. The analysis which will be presented in this paper will however be steady state, based on average daily moisture production rates and essentially single cell. A more complex analysis will be developed in due course. The additional ventilation required to remove moisture over and above the background ventilation of the dwelling is influenced by a number of factors, some of the most important are:

the rate of moisture production in the dwelling
the moisture content of the outside air
the air temperature of the dwelling
the air tightness of the dwelling
the moisture absorbtion of the structure and furniture
the dwelling size
whether trickle vents are open or closed
the proportion of moisture removed in the kitchen or bathroom

Manually controlled systems have not been considered because their use and hence relative performace, is dependent on human behaviour and there is little information available. An important factor in the calculations is that the effect of an extract fan or a passive stack ventilator is not simply additive to the total ventilation. The addition of the extract fan or PSV changes the pressure distribution in the dwelling. Calculations using the single cell ventilation model BREVENT (ref 1), suggest a reduction factor to the flow through the device of about 0.5 applies for PSV and 0.6 for fans in the range of interest. Initial calculations are given for uncontrolled PSV and then later for controlled PSV.

## 2. THE CALCULATIONS

2.1 Energy calculations have been carried out for a range of rates of moisture production up to 16kg per day, the maximum for a very wet household given in BS 5250 (reference 4). The calculations have been carried out month by month over a heating season from October to April inclusive taking average conditions of outside moisture and outside temperature for each month. Energy use has been calculated for three mean household temperatures, 14° C, 16°C and 18°C. (Results are only shown for 16°C and 18°C). These are typical figures for the UK from the English House Condition Survey (refs 2 and 3)

2.2 The calculations have been carried out on the basis of the equations below. The calculations at this stage are for uncontrolled PSV. The flow rate required to remove the moisture generated is given by:

$$Q_1 = \frac{G}{\rho_{air}(g_{70} - g_{outside})} \tag{1}$$

from Milbank reference (5) which is the same as the methodology given in BS5250 reference (4) and Meyringer reference (8), (although the precise equation is somewhat different).

If a proportion $\alpha$ of the moisture is removed in the kitchen, and if the extract rate of the fan is $Q_3$ $m^3$/day then the proportion of the day for which the fan runs will be

$$\alpha \frac{Q_1}{Q_3} \tag{2}$$

The remainder of the moisture will be absorbed and/or will spread around the rest of the dwelling to be desorbed later. This moisture may require the fan to run to provide additional ventilation. When the extract fan (or PSV) is applied to the whole house then for the reasons given earlier the additional flow is less than the actual fan flow rate. If we call the reduction factor B then if $Q_2$ is the background ventilation rate in $m^3$/day then the proportion of the day for which the extract fan will run in order to clear the rest of the moisture is given by:

$$\frac{(1-\alpha)\ Q_1 - Q_2}{B_f\ Q_3} \tag{3}$$

If the fan is operated by a humidistat this quantity cannot be negative.

The energy use arising from the fan airflow may be expressed by:

Fan <u>airflow</u> energy use =

$$\rho_{air}\ \frac{B_f\ Q_3}{E_1}\left[\frac{(1-\alpha)\ Q_1 - Q_2}{B_f\ Q_3} + \alpha\ \frac{Q_1}{Q_3}\right] \Delta T \quad (KJ/day) \tag{4}$$

where the specific heat of air is taken as 1. KJ/Kg °K

The primary energy used by the fan is given by

$$\frac{P}{E_2}\ 24\left[\frac{(1\ -\ \alpha)\ Q_1\ -\ Q_2}{B_f\ Q_3} + \alpha\frac{Q_1}{Q_3}\right] 3.6\ KJ/day \tag{5}$$

The uncontrolled PSV energy use is given by:

$$\frac{\rho_{air}\ B_{psv}}{E_1}\ Q_4\ \Delta T \qquad KJ/day \tag{6}$$

These equations have been used to plot figures 1-3. The PSV system consists of a 125mm PSV in the kitchen and 100mm PSV in the bathroom. The fan system comprises a 68 litre/sec fan in the kitchen and a 25 litre/sec fan in the bathroom. Total fan power is 75W. The efficiency of electricity generation and supply is taken to be 30% and that of the boiler as 80%. The airtightness has been taken as 7 AC/hour at 50 pa in figures 1 and 2, which is fairly tight but likely to be typical under the revised UK Building Regulations and 10 AC/hour at 50 pa in fig 3. No direct account has been taken of moisture absorbtion as such although the steady state average calculation implies absorbtion and desorption. A 200$m^3$ dwelling has been chosen. Calculations were carried out with trickle vents closed. The corresponding whole house airflow rates were obtained from BREVENT taking a 4m/s wind speed, and background airflow rate was adjusted each month for temperature. It has been assumed that 50% of moisture is removed in the kitchen when the fan is running. It can be seen that PSV uses less energy with colder more airtight dwellings and where the rate of moisture production is high.

2.3 Another approach to the problem is to calculate the level of G, the moisture production rate at which PSV and extract fan energy use are equal. In general this will be done for seasonal averages. From equations (4), (5) and (6) PSV energy use is greater than extract fan energy use if:-

$$\frac{\rho_{air} B_{psv}}{E_1} Q_4 \, \Delta T > \frac{\rho_{air} B_f Q_3}{E_1} \left[ \frac{(1-\alpha) \, Q_1 - Q_2}{B_f Q_3} + \alpha \frac{Q_1}{Q_3} \right] \Delta T \tag{7}$$

$$+ \; 86.4 \, \frac{P}{E_2} \left[ \frac{(1 - \alpha) \, Q_1 - Q_2}{B_f Q_3} + \alpha \frac{Q_1}{Q_3} \right]$$

If we call the proportion of the time for which the fan runs $\gamma$

$$\left[ \frac{(1 - \alpha) \, Q_1 - Q_2}{B_f Q_3} + \alpha \frac{Q_1}{Q_3} \right] = \gamma \tag{8}$$

then PSV energy > fan energy if

$$\frac{\rho_{air}}{E_1} \Delta \, T \, (B_{psv} \, Q_4 - \gamma \, B_f \, Q_3) > 86.4 \, \frac{P}{E_2} \, \gamma \tag{9}$$

If equation 9 is made into an equality it can be solved for $\gamma$ and hence from equations (8) and (1), $G_o$ can be obtained.

## 2.4 The effect of varying the proportion of moisture removed in the kitchen

From equations (1) and (8) it can be shown that where $Q_2 < (1 - \alpha) \, Q_1$

$$\frac{1}{\frac{1}{B_f Q_3} - \alpha \left( \frac{1}{B_f Q_3} - \frac{1}{Q_3} \right)} \tag{10}$$

G is proportional to $Q_1$ which is proportional to

Thus the smaller $\alpha$, the lower the value of $G_o$ . Where however, $Q_2 > (1 - \alpha) Q_1$ , $G_o$ is proportional to $\alpha^{-1}$ and the smaller $\alpha$ the larger $G_o$.

This is illustrated in the table below for $T_{inside} = 16°C$, $T_{outside} = 7°C$, outside moisture = 5.5 g/kg and a house of 7AC/hour at 50pa.

| $\alpha$ | 0 | 0.25 | 0.5 | 0.75 | 1.0 |
|---|---|---|---|---|---|
| $G_o$ | 6.66 | 7.40 | 7.03 | 4.18 | 3.13 |

Table 1 - The effect of changing the proportion of moisture removed in the kitchen

There is little data which might be used as a guide to the appropriate value of $\alpha$. It might be reasonable to assume that half of the moisture generated in the kitchen or bathroom is removed in the kitchen or bathroom. A value nearer to 0.25 might be more appropriate. However, as can be seen from the table, it will not make a large difference to $G_o$. The effect of closing the kitchen door is of course equivalent to $\alpha = 1$.

## 2.5 Humidity Controlled PSV

For controlled PSV the flow rate has been calculated from the relative humidity obtained by linear interpretation of the psychometric chart and the consequent open area of the humidity control device using the following equation:

$$g_{inside} = g_{70} - (Q_2\ \rho_{air}\ (g_{70} - g_{outside}) - G)\ / Q_2\ \rho_{air} \qquad (11)$$

From linear extrapolation on the psychometric chart

$$RH = RH_0 + A\ (T_o - T_{ins}) + D\ (g_{inside} - g_o) \qquad (12)$$

where $T_{in}$ is the temperature in the house in °C

A and D are constants.

The open area of the humidity control device is given by:

$$A_1 = A_0 + (RH - RH_0)\ \frac{\Delta A}{\Delta RH} \qquad (13)$$

where $\Delta$ A is the range of area over the RH range $\Delta$ RH.

The PSV flow rate is given by:

$$Q_4 = B_{psv}\sqrt{\frac{2\Delta p}{\rho_{air}\left(\frac{k_1}{A_1^2}+\frac{k_2}{A_2^2}\right)}} \tag{14}$$

Where $k_1$ is the loss coefficient of the humidity control device and $k_2$ is the loss coefficient of the rest of the system. $\Delta p$ is the pressure generated by the stack effect. These coefficients were obtained from experimental data. A 4m/s wind speed was assumed throughout but flow was adjusted for changes in outside temperature. The calculation was iterated after the initial calculation of PSV flow rate using the initially calculated PSV flow rate adding this to the background ventilation rate and substituting in equation (11). A couple of iterations were carried out until the calculated PSV flow rate stabilised. The results are also shown in figures 1 to 3. The effect is to lower the cross over point between PSV and fans in terms of moisture production rate but perhaps more important to reduce significantly the difference between PSV and extract fans at low moisture production rates.

## 3. DISCUSSION

All the eight factors described in the introduction have a significant effect on the relative energy use of PSV and extract fans. Whilst calculations have not been shown for building volume, the effect is similar to that for airtightness by lowering or raising the background ventilation level. Moisture absorbtion has not been illustrated, but the effect is implicit in the use of a steady state analysis. Overall PSV is relatively more energy efficient:

the higher the moisture production rate
the higher the moisture content of outside air
the lower the temperature of the dwelling
the more airtight the dwelling
the lower the moisture absorbtion
the smaller the dwelling
with trickle vents closed
the more moisture spreads around the dwelling
if the kitchen door is closed.

and the opposite for extract fans.

The effect of humidity controlled PSV is to significantly reduce the energy penalty of PSV systems at low moisture production rates and to shift the crossover point to lower moisture levels. Thus it is clear that in some conditions extract fans have the lower energy use and in other conditions PSV has the lower energy use. It should be made clear however, that this is a steady state analysis and based on a single cell ventilation model and it would be unwise to be too precise about the cross over points. However the conditions shown are all within the range which will occur in practice.

## 4. ENERGY USE IN PRACTICE

There is little systematic evidence of the relative energy use of PSV and extract fans in practice. What little evidence there is (references 7 and 8) suggests that they are broadly comparable but as can be seen from figures 1 - 3 the differences in terms of overall dwelling energy use are relatively small. One is generally talking about a gigajoule or so per annum compared with about 50 gigajoule/annum for total energy use for a 200m$^3$ house, even with modern UK insulation levels. It would take either very precise experimental work with a lot of detailed measurements or a very large field study to discriminate to this level. In practice in the UK, PSV has been used almost exclusively in public sector housing and in very small owner occupied dwellings such as starter homes. Thus the analysis given above ties in with practical experience.

## 5. CONCLUSIONS

There is a need for a more precise dynamic, multicell analysis but within the limitations of the analysis presented above, it has been shown that the issue of energy use of PSV and extract fans is a complex one affected by at least eight independent variables. Within the range of these variables which occur in practice, sometimes extract fans have the lower energy use and sometimes PSV. Typically PSV both humidity controlled and uncontrolled is better from an energy point of view in a relatively cold, airtight small dwelling with high moisture production. At the other extreme fans will be more energy efficient in the warm leaky large dwelling with low moisture production.

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**fig1** house 200 cu m,7ac/hr at 50pa

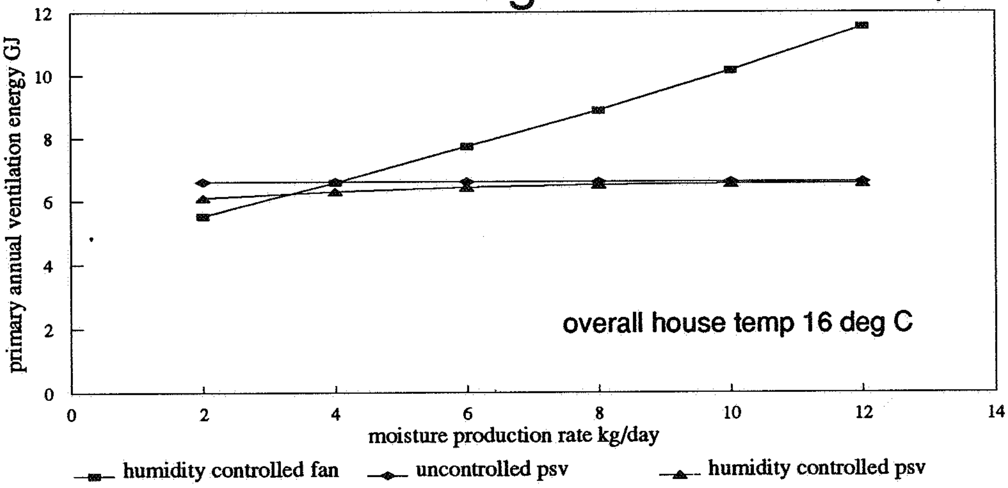

**fig2** house 200 cu m,7ac/hr at 50pa

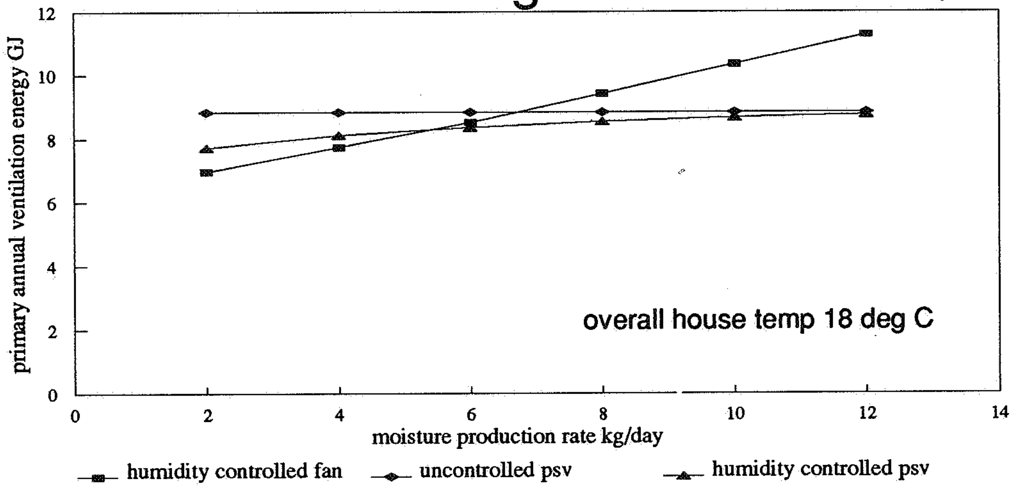

**fig3** house 200 cu m,10ac/hr at 50pa