OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
29 September - 2 October 1986

PAPER 16

THE USE OF PASSIVE VENTILATION SYSTEMS FOR CONDENSATION CONTROL IN DWELLINGS, AND THEIR EFFECT UPON ENERGY CONSUMPTION

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SYNOPSIS

The need for reduced energy consumption has led to an overall decrease of air infiltration rates in buildings, particularly in dwellings. Unfortunately, this has given rise to a significant number of problems involving condensation, with resulting damage to the structure and contents of affected buildings. Various means of condensation control are available. The use of a passive ventilation system to achieve this aim has several attractions, not the least of which is that the occupants of houses fitted with such a system need little, if any, knowledge of the principles involved, or instruction in its use, to derive maximum benefit.

This paper describes a program of work which compares the performance of a passive ventilation system, installed in the kitchen and bathroom of a house of timber framed construction, in comparison with the use of mechanical extraction, window head ventilators, and opening of windows, as alternative means of ventilation. Particular emphasis is placed upon the influences of wind speed and wind direction. Using the ventilation rate measurements in conjunction with dry and wet bulb temperature data, rates of moisture extraction due to the four different means of ventilation are calculated, and the effects upon condensation risks are assessed in the light of predicted minimum ventilation rates required to avoid condensation. Comparison of predicted minimum and measured ventilation rates leads to the estimation of the effect of each type of ventilation upon space heating energy consumption.

1. INTRODUCTION

Modern domestic energy conservation techniques have led to increases in both the thermal resistance and air tightness of the typical building envelope. The effect of increasing air tightness is to reduce the whole house ventilation rate, and hence to generally increase the moisture content of the air inside the house. The danger of condensation on cold surfaces within the occupied space is thus greatly increased. Considering that up to 12 kg of water can be released inside a house in a day[1], it is clear that some provision for removal of water vapour directly from areas of high production rate (for example, kitchen and bathroom) would be highly desirable. Several methods have been suggested, for instance extraction fans and dehumidifiers.

One method of moisture extraction which has recently been put forward as a means of reducing condensation problems in the United Kingdom is the use of passive ventilation systems[2]. (It should be acknowledged that such systems have been in use in the rest of Europe for a signficiant length of time). Such systems use ductwork, terminating at roof level, to provide direct extraction of air from areas of high moisture production: temperature induced buoyancy effects (the so-called "stack effect") and wind induced suction effects provide the driving force for extraction. The use of a passive ventilation system has several advantages: prominent among these are that the occupants of a house fitted with such a system can derive full benefit from its presence with no instruction in its use, and also that maintenance costs on such a system are negligible with mechanically driven alternatives.

The purpose of this paper is to briefly compare the performance of a passive ventilation system with three alternative methods, namely mechanical extraction by wall mounted fans, window head slot ventilators, and window opening: the effects of wind speed and wind direction difference are also demonstrated. The ventilation rates produced by each method of extraction are compared with a predicted minimum ventilation rate for condensation avoidance, and thus the effect of each type of method of ventilation is assessed. In addition, multiple tracer gas measurements have been used to measure the airflows, to and from areas of high moisture production, associated with each method of ventilation.

2. ASSESSMENT OF SIGNIFICANCE OF COMPONENTS OF PASSIVE VENTILATION DUCT FLOW

As has mentioned previously, the principle of passive ventilation relies upon the stack effect and wind-induced suction effects. At this juncture, it would be useful to assess the likely order of magnitude of the contribution of each mechanism to the overall passive ventilation effect. For the calculations described below, it is assumed that house air is at 50% relative humidity at 20°C, whilst outside air is at 100% relative humidity at 0°C.

Let us first consider the contribution of the stack effect. The maximum available pressure difference for buoyancy driven airflows in a duct (in Pascals) is given by:

$$Pb = (Do-Dh).h.g. \quad (1)$$

where

Do = air density at outside temperature = 1.2853 kg/m³.
Dh = air density at room temperature = 1.1906 kg/m³.
g = acceleration due to gravity (9.81 m/s²).
and
h = vertical duct length (metres)

The presence of a moving air stream across the duct discharge induces a velocity pressure, which can be given simply by:

$$P_V = \tfrac{1}{2}\,do.V^2 \qquad (2)$$

where V = velocity of the air stream (m/s)

The relative sizes of the two contributions are shown in Table 1, for both the kitchen and bathroom ducts. It can be seen that the contribution due to stack effect is likely to be smaller than the wind-induced component for both ducts. It should also be borne in mind that:

(a) these calculations do not take into account wind direction or the geometry of the duct termination unit at roof level;

(b) the overall flow through a duct of a given length and cross-section will be influenced by resistance effects.

Both of these two considerations will be discussed later on in this paper.

3. EXPERIMENTAL

(a) Details of test house

The house used for the site measurements is situated at Willow Park, near Chorley, and is part of the Central Lancashire New Town Development. It is a four bedroom detached residence, of timber frame construction, and is built to a special low energy design[3]. Figure 1 shows the plan layouts of the two floors of the house, together with an artist's impression of the exterior. It can be seen that, in addition to the bathroom, there is also an en-suite adjacent to the master bedroom. A passive system was fitted in this en-suite, with a view to further work, but was sealed off during this investigation. The whole house volume is approximately 320 m^3, of which the kitchen and bathroom comprise approximately 34 m^3 and 13 m^3 respectively.

The passive ventilation ductwork installed in the test house is of 150 mm x 100 mm rectangular cross-section. It is fabricated from UPVC, and is supplied complete with factory-applied rigid foam insulation, in order to minimise the risk of condensation within the duct itself during use. The ductwork layout used is shown in Figure 2. The terminals used are Glidevale type G5 tile ventilators, situated two-thirds of the way up the roof. Each ductwork system is connected to its terminal by means of a length of fibreglass insulated 100 mm diameter flexible duct. Each of the duct systems is terminated at ceiling level by means of a rectangular grille of adjustable open area.

(b) Measurement details

The ventilation and air movement measurements carried out during this investigation were performed using the multiple tracer gas apparatus developed at UMIST. This technique is well documented (see for example reference (4)) and will not be described here. With regard to ventilation measurements, tests were performed under the following sets of conditions for both the bathroom and kitchen:

i) No passive ventilation, windows and trickle ventilators closed;

ii) As per (i), but with trickle ventilators open;

iii) As per (i), but with windows open 2";

iv) Passive ventilation, windows and trickle ventilators closed;

v) As per (iv), but with trickle ventilators open;

vi) As per (iv), but with windows open 2".

Doors are closed, unless specifically mentioned. In addition to these single-cell tests, a handful of measurements were made of the two-way airflows between the kitchen and the rest of the ground floor, for various ventilation regimes. Duct air velocities, inside/outside temperatures and wind speed and direction were also monitored.

4. RESULTS AND DISCUSSION

Measured ventilation rate values, together with other relevant data, are presented in Table 2 (kitchen), and Table 3 (bathroom): two-way airflow values between kitchen and the rest of the house are shown in Table 4. From the data sets, the following points can be discerned:

(a) The passive ventilation system used is sensitive to wind speed and direction. From Table 2, it can be seen that an increase in wind speed from 2 m/s to 5 m/s from the West has the effect of raising the air velocity in the kitchen duct by between 27% and 40%, depending on room conditions. Table 4 shows that a south westerly wind gives an appreciable increase in kitchen duct flow rate: a 3.5 m/s south westerly wind gives a flow rate of 16.2 m^3/hr for the duct and trickle vent combination, compared to the 8.1 m^3/hr flow rate measured under a 5 m/s westerly wind. Bearing in mind that the house ridge runs east-west, it is probable that the reason for this increase is that the system terminal is under greater suction for a south westerly wind than for a westerly. From this observation, it might be inferred that certain wind directions might actually reduce the performance of the system: however, this study did not collect sufficient data to confirm or disprove this theory.

(b) Comparing Table 2 with Table 3, it can be seen that the bathroom duct outperforms the kitchen duct for a given wind speed and direction. For instance, for the case of a 2 m/s westerly wind, the bathroom duct gives an extraction rate which is approximately 40% greater than that of the kitchen duct. Such results are in direct conflict with the findings of Johnson et al.[2], who claim that a kitchen duct will consistently outperform a bathroom duct, due to the enhanced buoyancy effects present in the former case. It is the contention of the authors of this paper that (especially in view of the small temperature differences and duct sizes involved) the greater resistance to flow of the longer kitchen duct is far more dominant a factor than the increased stack effect, and hence the shorter bathroom duct should outperform the kitchen duct. To underline this point, it should be noted that, at a length of 3 m, the bathroom duct used during this study is 40% shorter than the 5 m long kitchen duct.

(c) Table 4 demonstrates the effect of having the kitchen door open. Whilst it cannot be denied that having the door open greatly increases the kitchen flow rate, it is also quite clear that this practice also leads to the migration of large amounts of moist kitchen air to the rest of the house. In view of the fact that the purpose of the passive ventilation duct is to remove moisture at source, it therefore follows that the practice of leaving the kitchen door open is ill-advised.

Aside from the above points, a particularly worrying discovery was made during this study. At wind speeds in excess of 9 m/s, the flow direction in the ducts actually reversed: in other words, the passive ducts were providing an inflow of air into the house. This discovery obviously puts a big question mark against the usefulness of passive systems at higher wind speeds. Further investigations are planned: at the moment, it is thought that this flow reversal is a function of the aerodynamic characteristics of the tile ventilator used. One suggestion which has been made is to make use of a ridge tile ventilator as a termination device. Unfortunately, the authors have shown[4] that flow reversal takes place in ridge tile ventilators at higher wind speeds, which is quite surprising in the light of the popular opinion that ridge tile ventilators are always in a state of suction.

5. ENERGY IMPLICATIONS OF DIFFERENT VENTILATION METHODS

At this point, it is appropriate to give some brief mention of the likely order of magnitude of minimum ventilation rate required in order to avoid surface condensation, and, in addition, to examine the energy penalties incurred by the use of the different ventilation regimes considered during this study. According to Meyringer [5], for a house of approximately 300 m^3 volume, with 3 or 4 occupants producing 12 kg of moisture per day, the minimum ventilation required to avoid surface condensation is likely to lie between 65 to 85 m^3/hr, corresponding to a whole house air change rate of between 0.22 to 0.28 ach. However, considering that the kitchen and bathroom are almost certain to be the areas of maximum moisture production, it is more appropriate to express individual minimum ventilation rates for these two rooms.

Taking the case of the kitchen, and assuming a daily moisture production of 6 kg, a minimum kitchen ventilation rate of between 0.96 and 1.25 ach is required, corresponding to a volume flow rate of between 32.5 to 42.5 m^3/hr. Similarly for the bathroom, assuming a daily moisture production rate of 2 kg, a minimum bathroom ventilation rate of between 0.85 and 1.1 ach is required, that is, a volume flow rate of between 11 and 14 m^3/hr. Examination of Tables 2 and 3 shows that use of a passive system in the kitchen gives ventilation rates of between 0.84 and 1.17 ach, whilst the bathroom system provides a ventilation rate of the order of 1.04 ach. Therefore, it can be seen that, under the test conditions experienced during this study, the use of a passive system should, in most cases, give a background ventilation rate which is adequate to prevent surface condensation.

Finally, Table 5 shows the ventilation energy penalties associated with various means of ventilation, together with an assessment of whether a specific method would satisfy the minimum ventilation criteria for the avoidance of surface condensation in the test house, as set out above. The quoted values are calculated on the basis of the energy required to heat the replacement air, at 0°C with 100% RH, to 20°C, with 60% RH. Two main points emerge: firstly, window head trickle ventilators fail to provide the necessary minimum ventilation rates in both the bathroom and kitchen: and secondly, the use of passive systems would appear to provide a very energy efficient means of moisture control for the test conditions experienced.

6. CONCLUSIONS

(1) The results obtained during this study would appear to indicate that under the test conditions experienced, the use of the passive systems provides a satisfactory, energy efficient means of condensation control.

(2) However, the study has shown that the systems are extremely sensitive to wind fluctuations, both in speed and direction. Because of this, the authors are far from convinced that the passive system used during this study would provide the minimum ventilation rates necessary to avoid surface condensation over the whole range of wind conditions likely to be experienced during day to day use. In particular, the phenomenon of flow reversal at higher wind speeds gives great cause for concern.

(3) The practice of leaving doors open in order to increase duct flow rates is not to be recommended, since it encourages the migration of warm, moist air to other parts of the house.

(4) In view of the possibility of a requirement for some form of passive ventilation provision becoming enshrined in the Building Regulations, it is essential that a far more broad based, extensive study of the operation of passive ventilation systems of differing configurations is carried out, with the intention of both identifying the optimum design, and quantifying the optimum performance which can be achieved.

(5) It is felt that particular attention should be given to roof terminator design, in order to produce a terminator which avoids flow reversal at higher wind speeds, satisfies existing rain penetration criteria, whilst fulfilling the requirements of architectural aesthetics.

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Duct Length	Pressure induced bystack effect[Pa]	Wind induced pressure m/s Pa		
		2	4	6
1	0.93	2.57	10.28	23.14
3	2.78	"	"	"
5	2.78	"	"	"
7	6.51	"	"	"

TABLE 1

Pressure components in duct system due to stack effect and windspeed.

	N_K		Duct Flow		% of N_K				
Conditions	ACH	m³/hr	m/s	m³/hr	due to duct		Speed (m/s)	Direct.	Δ T°C
All sealed	.23	7.82	-	-	-	-	2	W	11
Trickle vents open	.59	20.06	-	-	-	-	2	W	12
Duct and trickle vent open	.84	28.56	0.11	5.9	20.7	-	2	W	12
Duct and windows 2"	3.00	102.00	0.15	8.1	7.9	-	2	W	12
Duct open only	.37	12.58	0.10	5.4	42.9	-	2	W	12
Windows open 2" only	2.57	87.38	-	-	-	-	2	W	12
All sealed	.31	10.54	-	-	-	-	5	W	13
Trickle vents open	.63	21.42	-	-	-	-	5	W	13
Duct and trickle vent open	1.17	39.78	0.15	8.1	20.3	-	5	W	12
Duct and windows 2"	3.67	124.78	0.25	13.5	10.8	-	5	W	12
Duct open only	.53	18.02	0.14	7.6	42.2	-	5	W	12
Windows open 2" only	2.74	93.16	-	-	-	-	6	W	13

TABLE 2 : Results for kitchen ventilation tests

Conditions	N_B ACH	N_B m^3/hr	Duct flow m/s	Duct flow m^3/hr	% of N_B due to duct	Wind Speed (m/s)	Wind Direct.	Δ T°C
All sealed	.35	4.55	-	-	-	2	W	14
Trickle vent open	.58	7.54	-	-	-	2	W	14
Duct and trickle vent open	1.04	13.52	.16	8.6	63.6	2	W	14
Duct and windows 2"	3.19	41.47	.24	12.9	31.1	2	W	14
Duct open only	1.03	13.39	.15	8.1	60.5	2	W	14
Windows open 2"	2.72	35.36	-	-	-	2	W	14

TABLE 3 : Results for bathroom ventilation tests

Conditions	N_K ACH	N_K m³/hr	N_H ACH	N_H m³/hr	$F_{K\ H}$ m³/hr	F_{H-K} m/s	Duct flow m/s	Duct flow m³/hr	Wind Speed (m/s)	Wind Direct.	T°C
Door shut, trickle vents open	.55	18.7	.20	64.0	10	10	-	-	3.5	SW	13
Door open, trickle vents open	1.29	43.9	.23	73.6	35	40	-	-	3.5	SW	13
Kitchen duct open, trickle vents open, door shut	1.12	38.1	.24	76.8	10	10	0.30	16.2	3.5	SW	13
Kitchen duct open, trickle vents open, door shut	3.00	102.0	.22	70.4	77	100	0.55	29.7	3.5	SW	13

TABLE 4 : Two-way flows between the kitchen and the rest of the house

ROOM	METHOD OF VENTILATION	VENTILATION RATE (m^3/hr)	ENERGY CONSUMPTION (KW)	MINIMUM RATE ACHIEVED
Kitchen	Window head Vents open	20	0.25	No
	Passive vent + Window vents	34	0.42	Yes
	Kitchen windows open	89	1.1	Yes
	Extract fan	100	1.23	Yes
Bathroom	Window head vents	7.5	0.1	No
	Passive vent & Window vents	13.5	0.17	Yes
	Bathroom window open	35.5	0.43	Yes
	Extract fan	100	1.23	Yes

TABLE 5 : Ventilation energy penalty for different ventilation methods

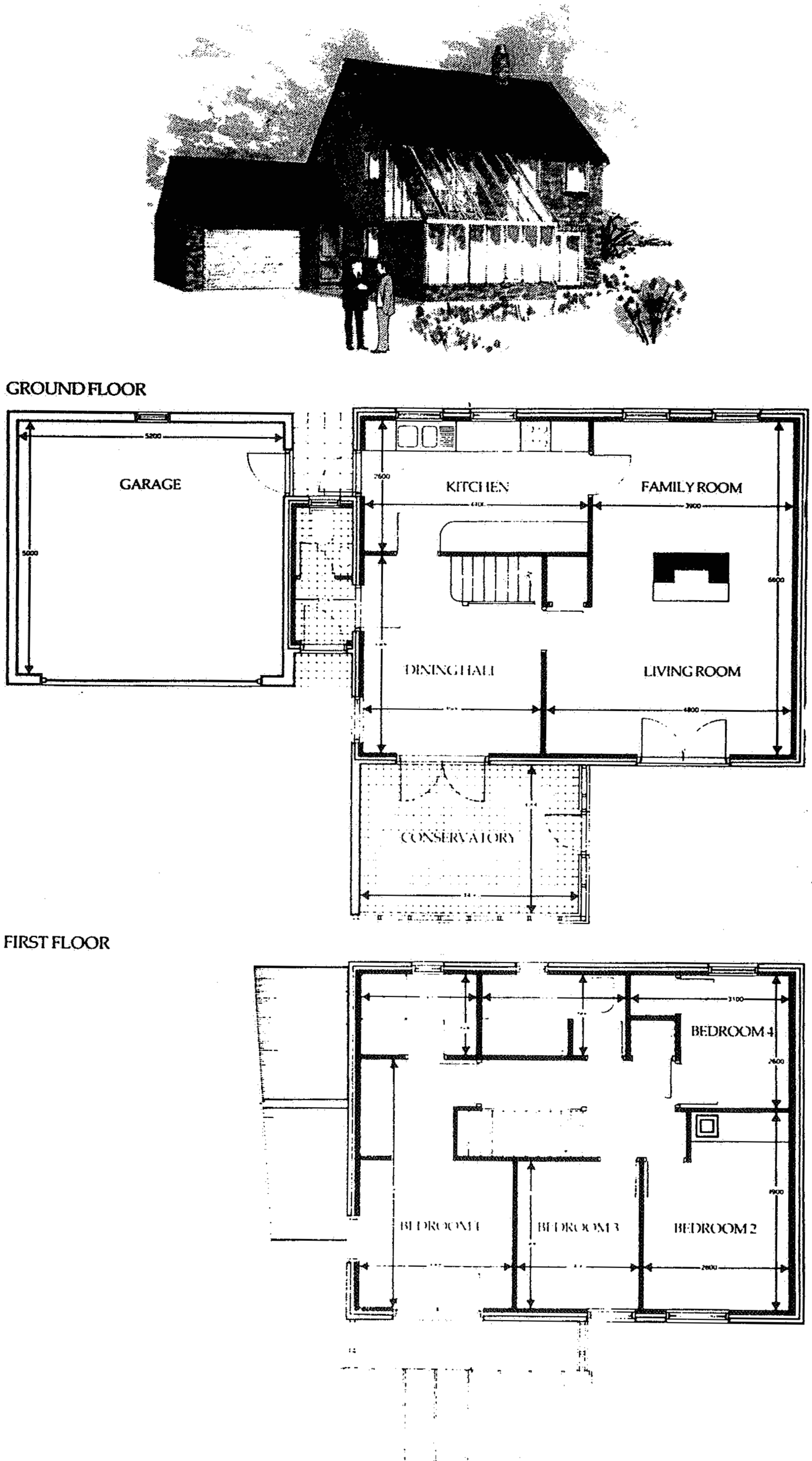

FIGURE 1: Test house

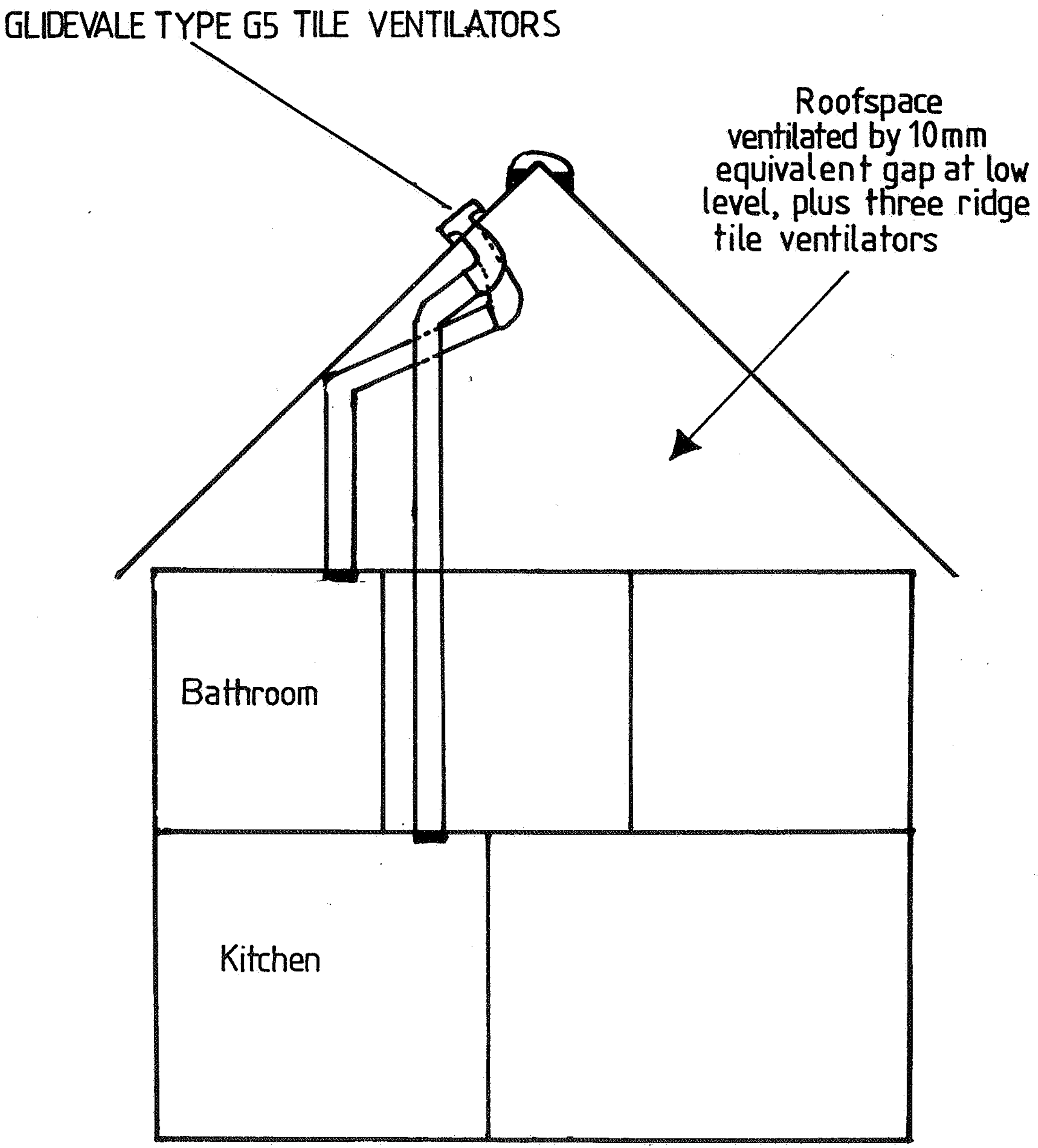

FIGURE 2: DUCT LAYOUT