EFFECTIVE VENTILATION

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FURTHER STUDIES OF PASSIVE VENTILATION SYSTEMS - ASSESSMENT OF DESIGN AND PERFORMANCE CRITERIA.

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ABSTRACT

Increases in building air tightness for purposes of energy saving have, unfortunately, also led to a significant increase in the number of instances of condensation damage, particularly in domestic properties. The cost effective control of condensation is a large problem in the United Kingdom, especially for local authorities with large housing stocks. The use of ducted passive ventilation systems, relying upon stack and wind effects to provide extraction, has several advantages, one of which is that the occupants of dwellings fitted with such systems need little, if any, knowledge of the principles involved, or instructions in its use, to derive maximum benefit.

This paper descirbes two programs of research carried out on two houses fitted with passive systems: the first house is a highly airtight, timber framed structure, whilst the second is a significantly leakier council owned property of traditional construction. The effect of passive ducts upon the ventilation rate in each dwelling is measured and related to internal/external temperature difference, windspeed and direction. The measured ventilation rates are used to calculate likely rates of moisture extraction during occupation, and the resulting effects upon condensation risk are assessed in the light of the predicted minimum ventilation rates neccessary in order to avoid condensation. Theoretical calculations of the expected flow rates through passive systems are presented, and are shown to be in broad agreement with measured values. Finally, design considerations of importance when specifying passive systems are discussed.

INTRODUCTION

Modern energy saving techniques have led to increased risks of condensation upon cold surfaces within the occupied spaces of dwellings. Batty et al (1) estimate that as much as 12kg of water can be released as vapour within a house in a day. It is clear that localized extraction of water vapour in high production rate areas (for example bathroom and kitchen) would be highly advantageous.

A simple, potentially cost effective method of moisture extraction which has been suggested as suitable for use in the United Kingdom is passive stack ventilation, or PSV.

(2) It should be noted that such systems have been in use in most of the rest of Europe for a substanstial length of time. These systems use ductwork, terminating at roof level, to provide direct extraction of moist air from areas of high moisture production. The driving forces for extraction are the temperature induced buoyancy force (the "stack effect") and wind induced suction. The likely orders of magnitude of each driving force can be estimated as follows. Firstly, the maximum available pressure difference for buoyancy driven airflow in a duct is given by

$$Pb = (po-ph).h.g \quad (1)$$

where po=air density at outside temperature (kg/m^3)
ph=air density at room temperature (kg/m^3)
h=vertical duct length (m)
g=acceleration due to gravity ($9.81m^2/s$)

Secondly, the velocity pressure difference induced by a moving airstream across the duct discharge, Pv, is given by

$$Pv=1/2.po.v2 \quad (2)$$

where v=velocity of airstream. (m/s)

Figures 1 and 2 show the pressure differences in a 5m high duct (typical of a kitchen installation) and a 1.5m high duct respectively, (typical of a bathroom installation.) Whilst figure 3 shows the effect of windspeed on wind induced pressure difference. It can be seen that in the majority of cases, the contribution of stack effect is likely to be smaller than the wind induced component: furthermore, the overall flow of air through a duct of a given length will be influenced by resistance effects.

The airflow rate through a duct can be calculated from the following formula:

$$Q=A[2A.Pt/(E.f.L.p)]^{\frac{1}{2}} \quad (3)$$

where Q=volumetric airflow rate (m^3/hr)
p=mean air density (kg/m^3)
Pt=total available pressure difference (Pa) $=[PB2+Pw2]^{\frac{1}{2}}$
a=cross-sectional area of duct (m^2)
E=perimeter of duct (m)
f=friction coefficient of duct (dimensionless)
L=length of duct (m)

Values calculated from equation (3) are then corrected using the procedure described in detail in reference (3), in order to take account of any air resistance within the ducts due to bends.

Figure 4 shows the calculated airflow through a 1.5m high, 100mm internal diameter duct for a range of internal/external temperature differences and windspeeds, whilst figure 5 gives the same information for a 5m high duct of the same internal diameter.

The main aims of the work described in this paper are threefold:

1) To assess the performance of PSV systems installed in two houses of different construction and air leakage characteristics, for a range of weather conditions;

2) To determine whether the contribution to the ventilation rate in the bathrooms and kitchens are suffient to avoid condensation in each house;

3) To estimate the effects of the use of PSV systems upon energy consumption, and to compare them with the effects of other means of moisture removal.

EXPERIMENTAL

a) Details of test houses.

The house used for the first site investigation is situated at Willow Park, Chorley, and is part of the Central Lancashire New Town development. The house is described in greater detail in reference (4), but, briefly, is of a special low energy timber frame construction. The whole house volume is approximately 320m^3, of which the bathroom and kitchen comprise approximately 13m^3 and 34m^3 respectively. Figure 6 gives details of the PSV systems used.

The house used for the second investigation is situated at Withington, South Manchester, and is a three bedroomed, semi-detatched council house of traditional construction. The whole house volume is approximately 200m^3, of which the bathroom and kitchen comprise approximately 6.7m^3 and 16.2m^3 respectively. Figure 7 gives details of the PSV systems installed. There are three main differences between the systems used in each house. Firstly, 150mm diameter insulated flexible duct is used in the council house installations instead of the previous rigid rectangular ductwork; secondly, the council house installations are terminated at ridge level by means of Redland gas flue Ridge Ventilators; and finally, Bahco registers are used as ceiling terminals in the council house installations.

b) Measurement details.

The ventilation and air movement measurement performed during these two site investigations were made using the multiple tracer gas technique developed at UMIST (5) Briefly, the technique uses a modified portable gas chromatograph, and is capable of measuring ventilation rates in, and airflows between, three interconnected cells.

The program of measurements performed in the low energy house is given in full in reference 4. The number of different permutations of test conditions used during this study was greater than for the council house study due to extreme airtightness of the house and the presence of window head trickle ventilators.

The following program of measurements was performed in the council house:

i) no PSV systems in use;
ii) bathroom PSV system in use;
iii)kitchen PSV system in use;
iV) both PSV systems in use;
In addition, the following subsidiary parameters were measured during each investigation:
i) internal/external temperature difference;
ii) air velocities in ducts;
iii)internal/external pressure differences;
iv) relative humidity in both kitchen and bathroom;
v) windspeed and direction.

RESULTS AND DISCUSSION.

a) Low energy house.

Measured ventilation rates, together with other data, are presented in table 1. (kitchen) and table 2. (bathroom). Several points are worthy of note:

i) The PSV systems are sensitive to windspeed. Table 1 shows that an increase in windspeed from 2m/s to 5m/s from the west increases the airflow rate in the kitchen duct by between 27% and 40%, depending upon room conditions. From other tests discussed in greater detail in reference it becomes apparent that both systems are highly susceptible to the influence of wind direction.

ii) Comparison of table 1 with table 2 shows that the bathroom system outperforms the kitchen system for the same windspeed and direction for example, for the case of a 2m/s westerly wind, the bathroom system extracts at a 40% higher rate than the kitchen system.

This is in conflict with the results of Johnson et al (5), who state that the greater stack effect in the longer kitchen duct will always lead to higher extraction rates in kitchen ducts as opposed to bathroom ducts. This argument does not, of course, take into account the influence of resistance effects due to duct length.

Equation 3 predicts duct airflows of approximately $33m^3/hr$ and $40m^3/hr$ for the bathroom and kitchen ducts respectively, for the test conditions experienced. It would appear that the extreme airtightness of the house has the effect of throttling the PSV systems. It is possible to increase duct airflow rates significantly by opening the kitchen door: however, air movement tests described in more detail in reference (4) show that this practice encourages the flow of moist air into the rest of the house, and is therefore not to be encouraged.

Aside from the other points mentioned above, it should be noted that at windspeeds in excess of 9m/s, the flow of air in both systems actually reversed, thus providing an inflow of air into the house.

b) Council House.

Measured ventilation rates, together with other data are presented in table 3 (kitchen) and table 4 (bathroom). Key features of the results are as follows:

i) As in the case of the low energy house, the systems are sensitive to the influence of wind speed, however, wind direction does not seem to have as significant an effect.

ii) Duct airflows are generally higher than for the low energy house. Table 5 compares duct airflows in both houses for comparable operating conditions.

iii) Airflow rates in the bathroom system are again higher than for the kitchen system under identical conditions. Expressed as a percentage of the overall air change rate, bathroom system airflow rates are comparable to those measured in the low energy house: for the kitchen system, however, the percentage is significantly higher.

iv) The effect of temperature upon duct airflows can be seen more clearly in this case. Temperature is the dominant factor at low wind speeds, but becomes less significant as wind speed increases. It can be seen that the measured airflow rates are in good agreement with the airflow rates predicted in figures 4 and 5.

V) flow reversal was again observed. However, in this case, the threshold windspeed for the onset of flow reversal was only 7m/s. Without carrying out a similar program of tests in a similar house, it is not possible to state categorically whether this reduction in threshold windspeed is due to the choice of terminal, or else is a function of building envelope air tightness. In the opinion of the authors, the former possibility is the more likely.

SYSTEM EFFECTIVENESS - ENERGY IMPLICATIONS OF PSV USE

Using the criteria outlined by Meyringer (6), and adjusting these in order to reflect the likely daily moisture production within the typical bathroom and kitchen, it is possible to estimate the minimum ventilation rates required in order to avoid surface condensation. These values are given in table 6. In the case of the low energy house, inspection of tables 1 and 2 shows that use of the bathroom PSV system gives a ventilation rate of approximately 1.04 ach, whilst the kitchen PSV system gives ventilation rates of between 0.84 and 1.1 ach. Thus it can be seen that even under the low wind speeds experienced during this study, the PSV systems should, in most cases, give a background ventilation rate which is adequate to prevent surface condensation. In the case of the council house, the PSV systems also give ventilation rates above the minimum; however, the rates are well in excess of the minimum required, and hence the systems could be wasting energy by over extraction. It could be argued that these calculations have been made on the basis of the assumption of a constant rate of moisture production and that in practice, higher rates of extraction might be of benefit in order to cope with peaks of moisture production. However, from the energy efficiency viewpoint, it is undesirable that over extraction takes place regularly. One possible solution to this problem would be the provision of a humidity-sensitive throttling system for each PSV duct installed in a house. Such a devise would preferably be non-electrically operated, in order to reduce the maintenance and running cost. Another solution might be to reduce the size of PSV ducts so as to give condensation control during conditions of average moisture production, whilst providing a humidity controlled booster fan in the PSV duct. Such a system would give a better response to rapid increases in moisture production rates, but would incur higher maintenance and running costs than the "humidity throttled" option.

d) Optimisation of system design.

In order to optimise the performance of a PSV system, several important design and installation points have to be taken into consideration:

i) The number of bends in a system should be minimised. Offsets or 135 degree bends are to be preferred in circumstances where bends are necessary; in any case, 90 degree bends should be avoided at all costs.

ii) Flexible ducts are valuable components to have available as an option when PSV systems are being designed. It is imperative, however, that when they are used, they are fully extended, or else the resistance to airflow resulting will be signigicantly greater than for a comparable length of rigid ductwork. It should be impressed upon installers that in circumstances where flexible ductwork is used that the ductwork should be cut to length, rather than allowing excess ductwork to hang loosely, or in the worst case, to be coiled up in the roofspace.

iii) It would be appropriate to remind any PSV system designer that the use of insulated ductwork in the roofspace is essential, in order to minimise the risk of condensation within ducts.

iv) On the basis of the results obtained in the two studies, it is recommended that, wherever possible, a PSV system should discharge by means of a ridge tile ventilator. The lower threshold windspeed for flow reversal is a small price to pay for the less wind direction sensitive system performance obtained.

v) The use of a common discharge terminal for two or more PSV systems may have a certain economic or aesthetic appeal. However, from a technical point of view, it is very important that each system in a dwelling discharges independently.

vi) The inferior performances of the PSV systems in the low energy house are due to an inadequate supply of air to feed the systems, underlining the importance which should be attached to the careful planning of airflow routes into and within a dwelling, in order to ensure that the PSV systmes operate to their full capabilities.

vii) If the dwelling being fitted with PSV systems is in an exposed area, it may be the case that volume control dampers have to be used in order to prevent over-extraction.

CONCLUSIONS.

Programs of test work on two contrasting types of house have shown that in both cases, PSV systems provide an efficient means of condensation control within zones of high water vapour producticn. However, the two studies serve to emphasise two contrasting factors which should be taken into account when designing PSV systems.

The extreme airtightness of the low energy house prevents the PSV systems form extracting to their predicted capability, whilst in the council house, it's high background air leakage means that over extraction is likely to occur, particularly at high wind speeds. On the one hand, it is essential to provide adequate air inlets so as to feed ducts, on the other, it is important to minimise over extraction for reasons of energy efficiency. Over extraction is best controlled by one of two means; firstly, by providing humidity-sensitive throttling of ducts; or secondly, by providing a mechanical boost to extraction. Two installations using the former principle are currently undergoing field trials.

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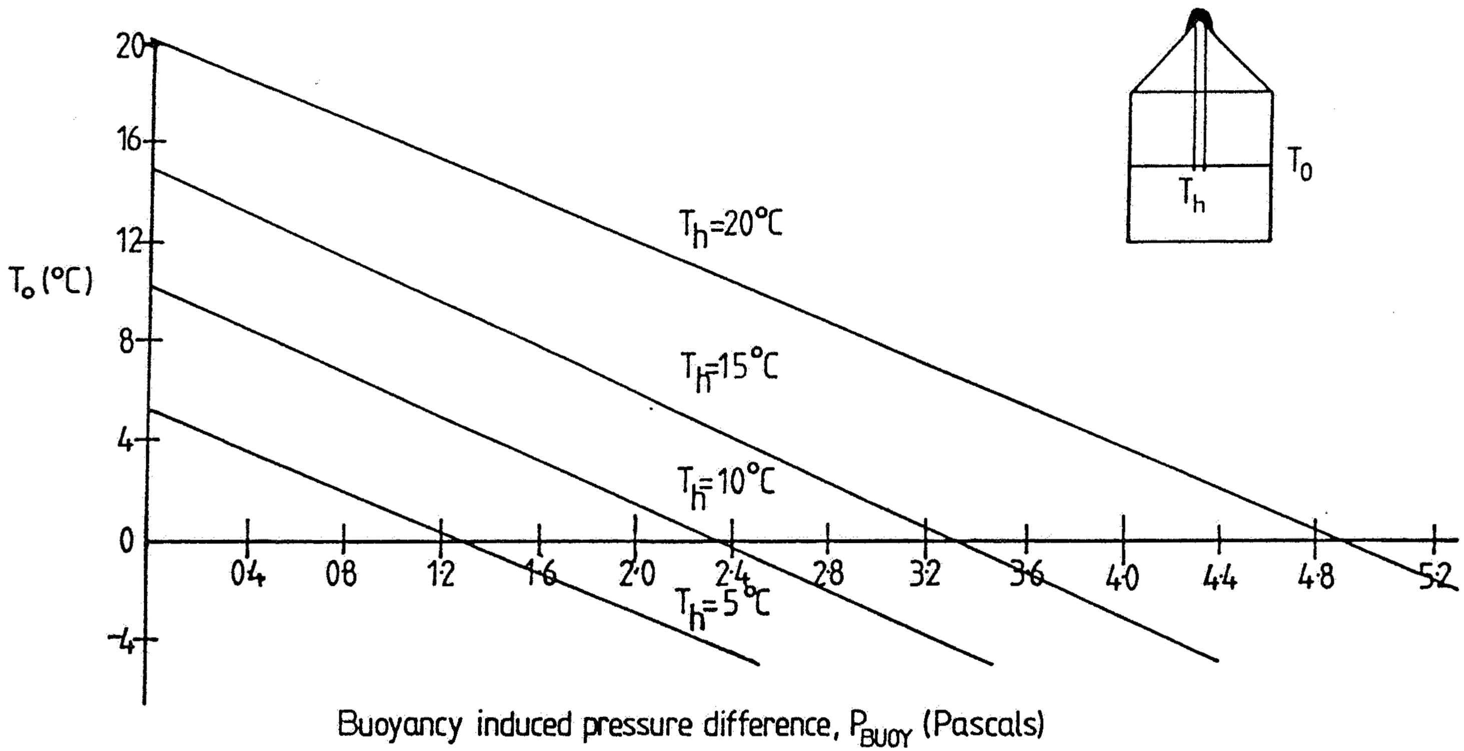

Figure 1: Buoyancy induced pressure difference 5 mtr duct.

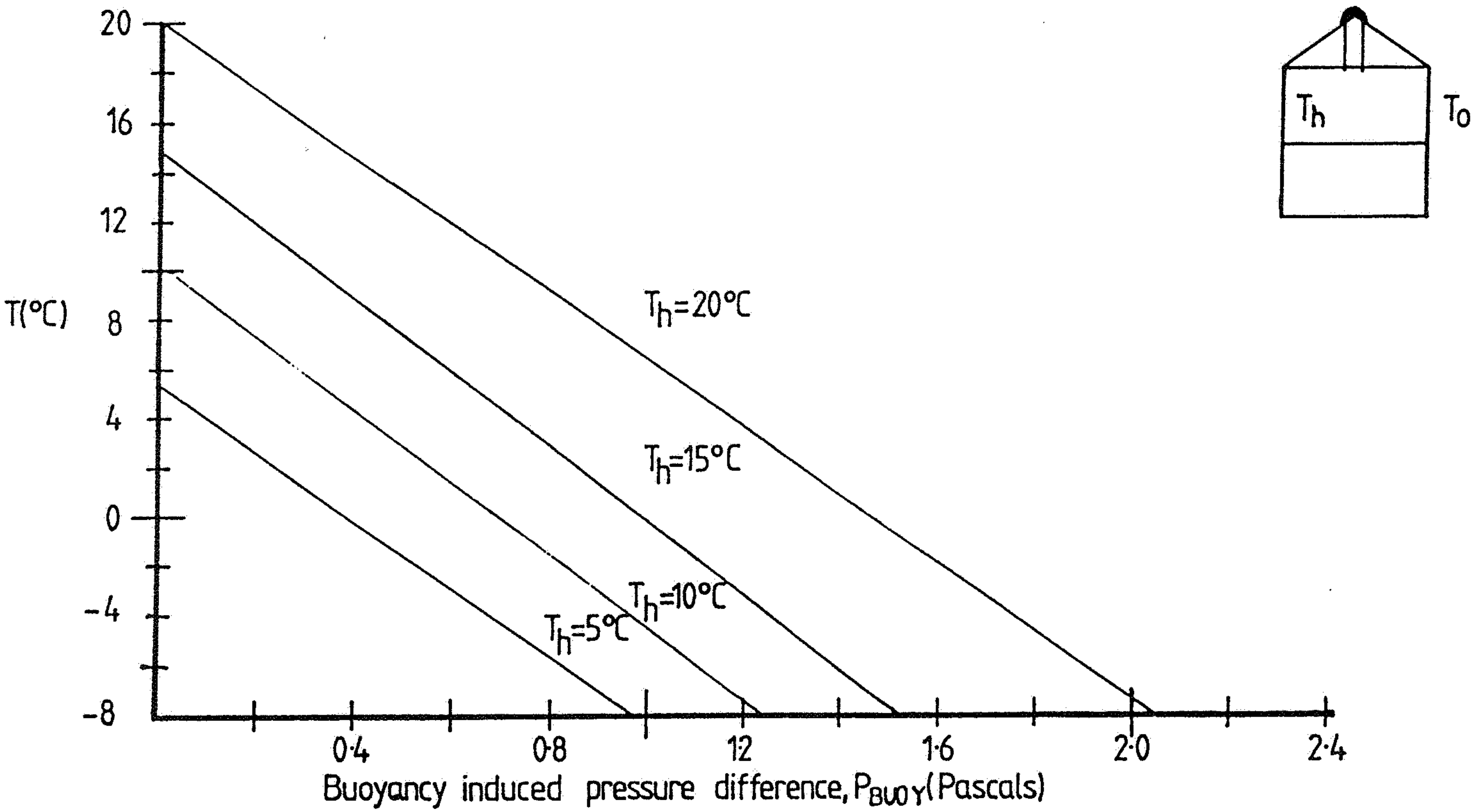

Figure 2: Buoyancy induced pressure difference1.5 mtr duct.

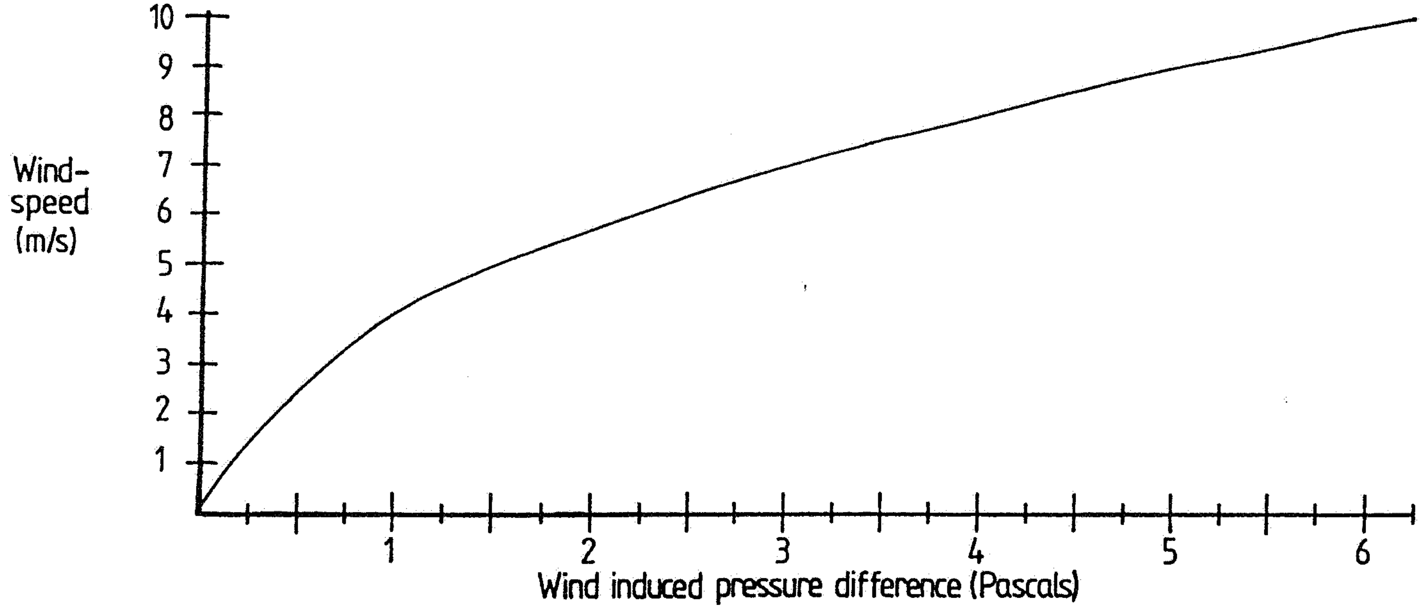

Figure 3: Wind induced pressure difference.

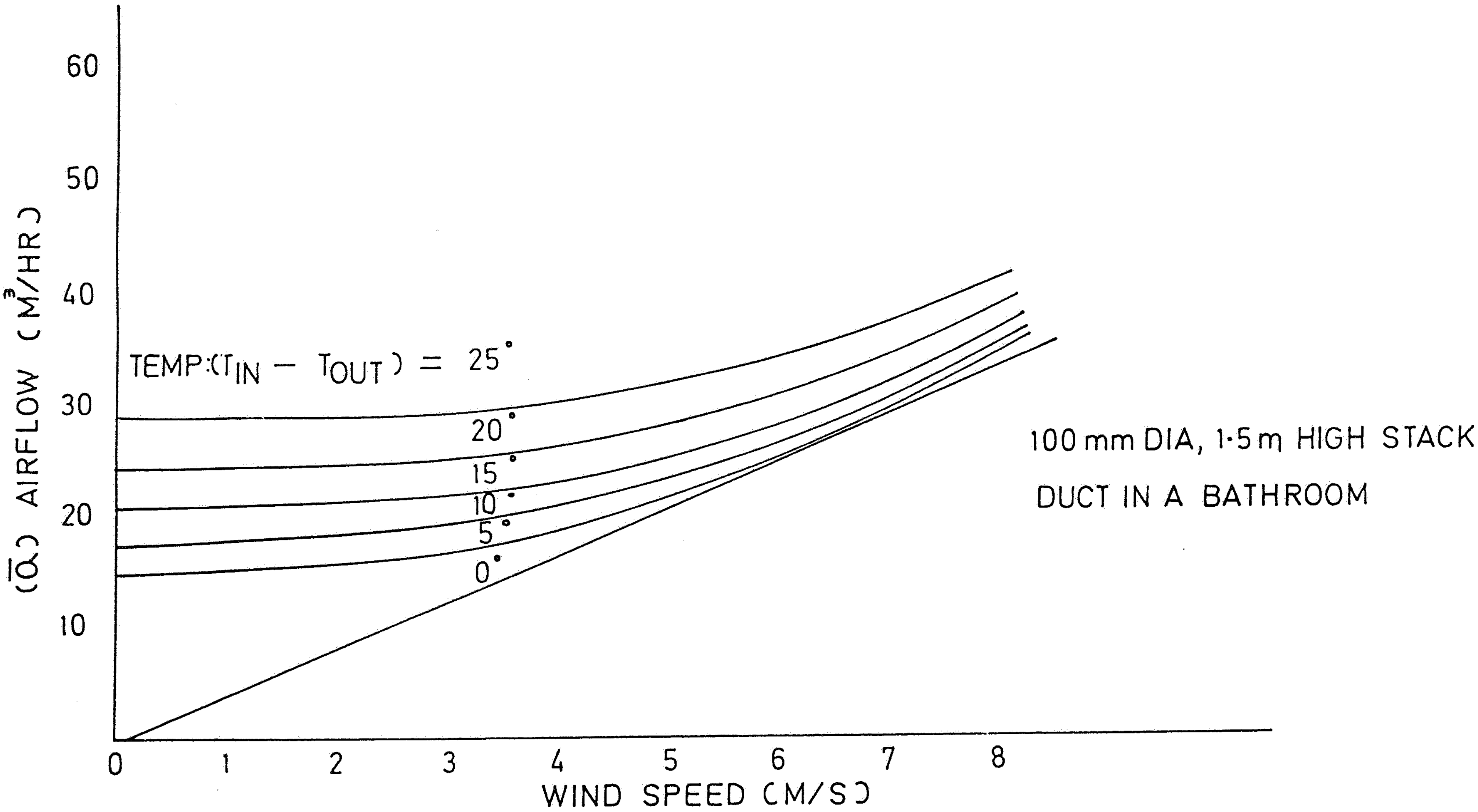

Figure 4: Calculated airflow 1.5 mtr high, 100 mm dia duct.

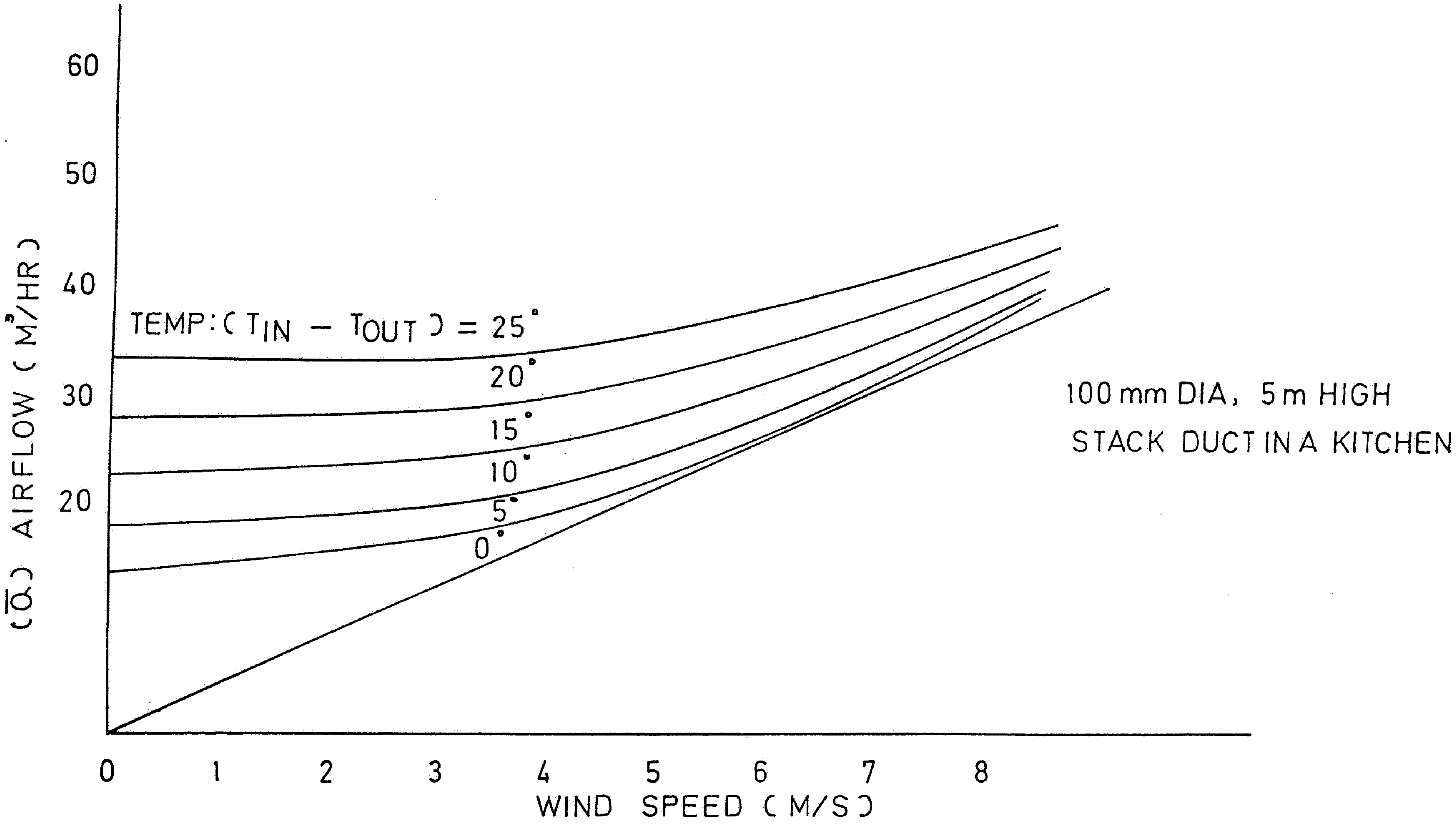

Figure 5: Calculated airflow 5 mtr high, 100 mm dia duct.

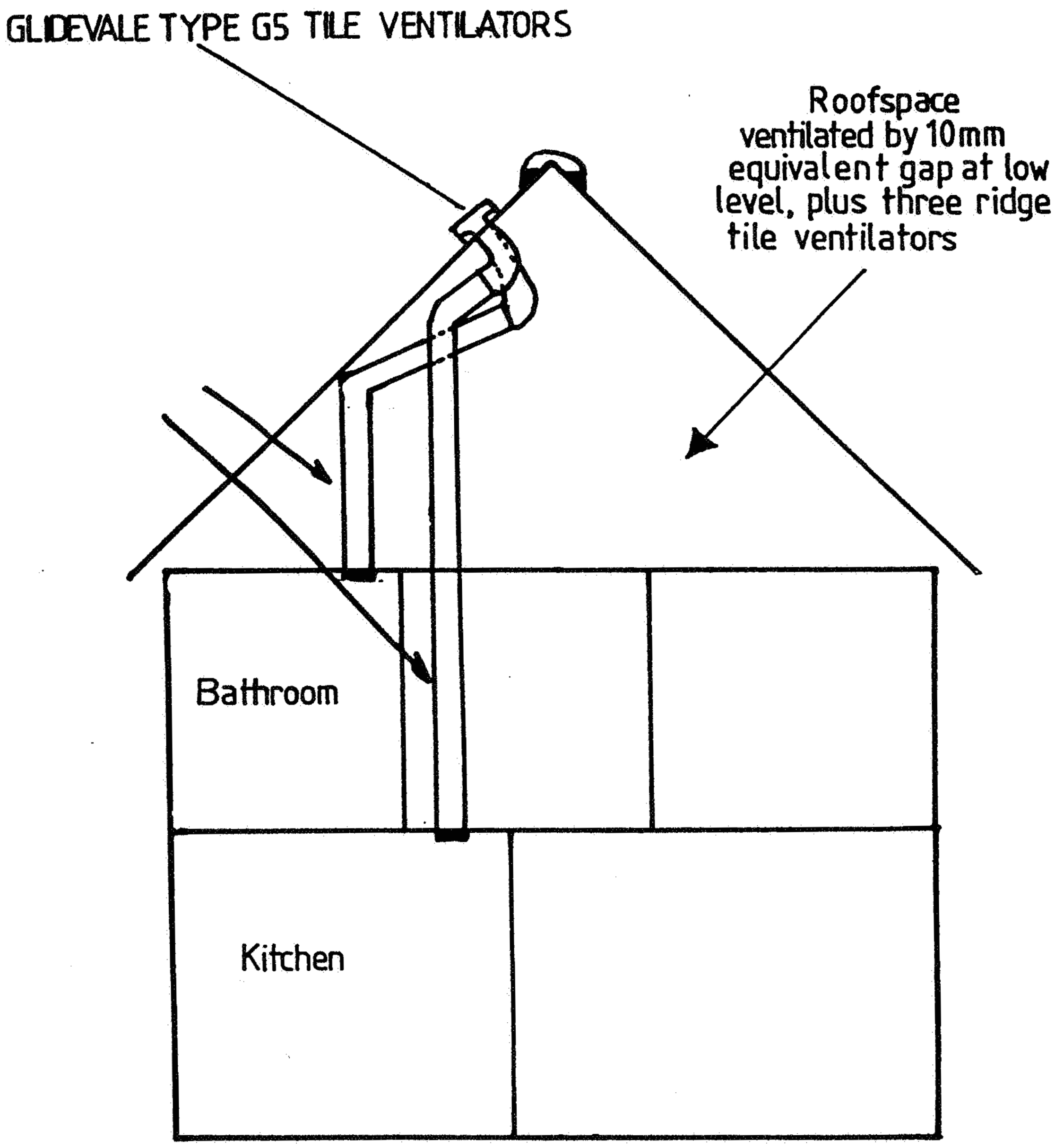

Figure 6: PSV Layout: Low energy house.

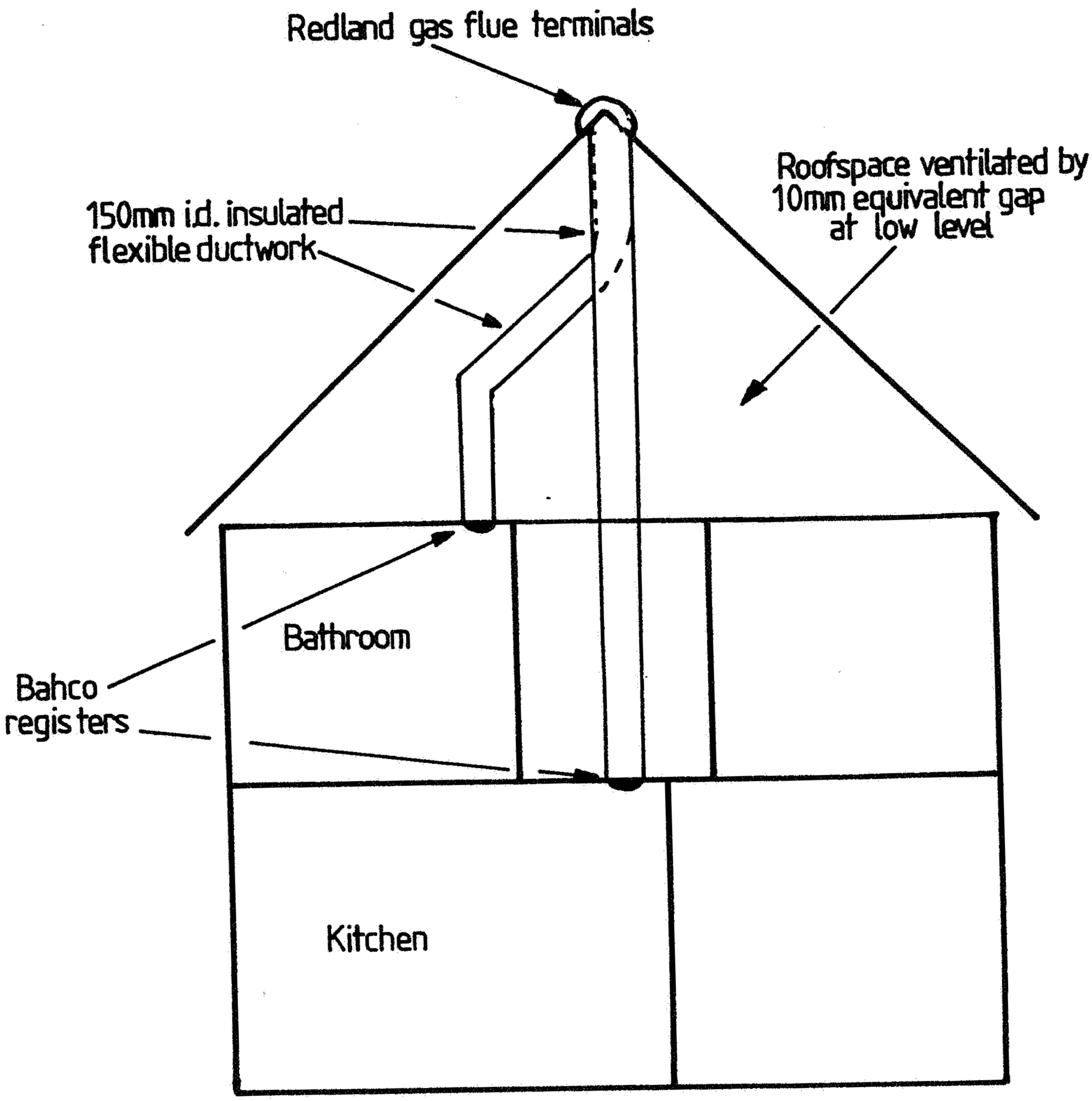

Figure 7: PSV Layout: Council House.

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Tables

Conditions	NK ACH	NK m^3/hr	Duct Flow m/s	Duct Flow m^3/hr	% of NK due to duct		Speed (m/s)	Direct.	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 1: Results for kitchen ventilation tests

Conditions	NB		Duct flow		% of NB	Wind		
	ACH	m^3/hr	m/s	m^3/hr	due to duct	Speed (m/s)	Direct.	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 2: Results for bathroom ventilation tests

Nk		Duct Airflow			Wind		
ach	m^3/hr	m^3/hr	% of Nk	T°C	Direction	Speed (m/s)	Comments
1.661	26.9	-	-	26.2	SE	3.0	Duct Sealed
1.956	31.7	-	-	14.5	S	5.0	" "
.939	15.2	-	-	10.0	W	3.5	" "
1.100	17.8	-	-	14.1	NE	6.5	" "
1.195	19.4	13.1	67.5	7.5	SW	3.0	Duct Open
2.226	36.1	20.4	56.5	15.4	SW	4.0	" "
2.808	45.5	20.4	44.8	18.9	S	5.0	" "
3.055	49.5	18.9	38.2	16.9	S	5.5	" "
1.568	25.4	11.7	46.1	9.0	NE	6.5	" "
1.297	21.0	14.6	60.6	13.7	NE	6.0	" "
2.139	34.7	18.9	54.4	9.3	S	6.0	" "
2.029	32.9	17.5	53.2	9.3	S	5.5	" "
1.197	19.4	14.6	75.2	9.2	SE	2.0	" "

Table 3: Council house kitchen

NB		Duct Airflow		T°C	Wind		Comments
ach	m³/hr	m³/hr	% of Nk		Direction	Speed (m/s)	
1.236	8.3	-	-	21.4	SE	3.0	Duct Sealed
1.743	11.7	-	-	15.8	S	4.0	" "
1.319	9.3	-	-	18.2	SE	4.5	" "
2.006	13.5	-	-	14.5	S	5.0	" "
4.251	28.6	20.4	71.3	29.3	S	5.0	Duct Open
4.580	30.8	21.9	71.1	24.5	S	5.5	" "
5.11[illegible]	34.4	23.3	67.7	22.2	S	6.0	" "
4.633	31.2	20.4	65.4	24.6	SW	4.0	" "
5.038	33.9	20.4	60.2	22.0	SW	5.0	" "
3.106	20.9	13.1	73.2	8.7	SW	6.0	" "
3.316	22.3	14.6	65.5	12.7	NE	6.0	" "
3.416	22.9	17.4	75.9	16.1	NE	6.0	" "
3.864	25.9	20.4	78.8	17.1	NE	6.0	" "
2.799	18.8	13.1	69.7	9.6	W	3.5	" "
3.106	20.9	13.1	62.7	10.0	W	6.0	" "

Table 4: Council house bathroom

House	Kitchen Duct Airflow (m^3/hr)	Bathroom Duct Airflow (m^3/hr)
Low Energy	5.9 - 8.1	16.5
Council	8.1 - 12.9	18.9

Table 5: Comparison of System Performances

House	Minimum Ventilation Rate			
	Kitchen		Bathroom	
	ach	m ³/hr	ach	m²/hr
Low Energy	0.96 - 1.25	32.5 - 42.5	0.85 - 1.1	11 - 14.0
Council	0.96 - 1.25	15.5 - 20.25	0.85 - 1.1	5.6 - 7.1

Table 6: Minimum Ventilation Rates