OPPORTUNITIES FOR ENERGY CONSERVATION BY HEAT PUMP DEHUMIDIFIER AND ODOUR TREATMENT

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Abstract

Ventilation becomes progressively more important as fabric insulation improves. The occupier's minimum needs are based on dilution of body odours. Behavioural studies show the occupier has a major influence on seasonal ventilation by opening windows. One reason for this is to avoid condensation.

Two electrical solutions to the ventilation problem are described. The first is a combined ozone and ultra violet irradiation to oxidize the mal-odours. The second is the application of a heat pump dehumidifier to remove excess moisture in mild weather.

1. INTRODUCTION

A building loses energy principally through two mechanisms. Traditionally the most important one is conduction through the building fabric. The measure of this is the thermal transmittance or 'U' value. The rising cost of energy has concentrated attention on this mechanism and there are a wide range of proprietary techniques to improve the insulation. For the roof the insulation is a thick blanket of mineral wool; for the walls it is a cavity insulant such as pelletised mineral wool, slabs of siliconed semi-rigid mineral wool or a ureaformaldehyde foam injection; for solid floors it is edge insulation set in the ground, while timber floors can have mineral wool packed underneath; the windows can be insulated and weather-stripped by numerous products. In a $90m^2$ British semi-detached house the use of these insulation methods can reduce the fabric conduction from 5.0 kW to 2.2 kW, fig. 1. This reduction, when taken with the benefits of the 'free' heat generated within the house, should have a powerful influence on energy saving.[1]

The second mechanism is the infiltration of cold air which displaces the warm air in the building. This ventilation heat loss is normally treated arbitrarily at one fresh air change per hour. Calculation techniques are available which are based on the knowledge of the infiltration coefficient of the window frame and the local wind conditions. [2] British houses largely use wooden window frames and the natural characteristics of timber make an infiltration coefficient difficult to estimate. Recent data by Skinner [3] shows that a significant part of the infiltration comes from casual gaps in the construction particularly the joint between masonry and wooden frames. Actual measurements of air changes by Warren of BRE [4] have revealed a wide difference between houses. Values from 0.3-1.4 air changes/hour are found at average wind speeds of 5 m/s. Each house then has its own variability with changes in wind speed, direction and temperature difference inside/outside. In badly insulated houses this notional heat loss is assumed to be 20-25% of the total heat loss. However in the well insulated house this approaches 50% of the design heat loss.

In larger buildings such as schools, the conventional assumption is two air changes per hour which comprises typically 35% of the design heat loss. In new prototype insulated schools meeting the same standards, the ventilation is 55% of the heat loss. Offices are similar.

This shows that ventilation is rapidly becoming the one major heat loss parameter. It is important for design sizing of space heating equipment. It is becoming important in terms of seasonal energy use, since careless ventilation can negate much of the benefit of fabric insulation. Let us therefore examine the ventilation criteria.

2. VENTILATION CRITERIA

Fresh air is needed to supply the physiological needs of metabolism and also to dilute the level of normal contamination to one which is both acceptable and safe. The contamination can be body odours in a crowded room, smoking, or moisture build up. These are considered individually.

(a) Physiological considerations

The chemistry of metabolism utilises the oxygen absorbed to generate carbon dioxide which is expelled. Tolerance to oxygen is particularly wide and it is most improbable that shortage of oxygen will ever occur in buildings. Breathing is controlled by the carbon dioxide level in the room. Depth of breathing increases at 2% carbon dioxide with a conscious effort increasing with higher concentrations to 6% which is dangerous. [5] The maximum allowable concentration of carbon dioxide is 0.5% by volume which gives a generous margin for breathing comfort. This is $4.5 m^3/h$ for a sedentary person, fig. 2.

(b) Odour dilution

Healthy, clean people give off odours even after a bath. Such odours are not known to be harmful but do induce unpleasantness. Malodours are rarely single compounds but complex mixtures. Yaglou, Riley & Coggins [6] published the basic research on which most ventilation codes are based. Odour generation was related to the elapsed time since the last bath. Children were more odorous than adults. The amount of fresh air needed to dilute these odours to an acceptable level was a function of both personal space and concentration level. Cigarette smoking introduces its own contaminants of particulates, acrolein and carbon monoxide. British practice is to double the minimum ventilation rate when smoking is permitted. [7]

Becher and Evensen [8] found that over the range of ventilation possible in Danish flats, the air quality was more related to the cleanliness and habits of the occupants than to the detailed measurement of the fresh air supply.

(c) Moisture

People continuously lose moisture. Part is respiration, part insensible perspiration through the skin and the remainder through the sweat glands when overheating has occurred. In normal circumstances a healthy 70 kg man working in a temperate climate loses approximately 400g of moisture a day from the lungs and a further 500g through the skin. The total moisture rate is 30g/h during sleep, rising to 40g/h while awake. This moisture level can become a contaminant in areas where humidity control is desired. In houses the personal moisture loss is reinforced by evaporation from washing, eating, cooking and clothes drying.

Current comfort recommendations are between 40-70% relative humidity. Lower values run the risk of electrostatic shocks and higher values can lead to fungus growths and building deterioration.

The amount of fresh air needed to dilute moisture levels to an acceptable value depends upon the absolute dryness of the outside air. In cold weather when the moisture content is low a small amount of air is sufficient. However there is a close relationship in Britain between the outdoor temperature and the absolute moisture content. [9] This means that in milder weather considerably more ventilation is needed to remove the same moisture.

3. THE OCCUPANT'S INFLUENCE

The occupier of the building can influence energy consumption by adjustment of temperature levels in both space and time. Less obviously he can affect the energy use by opening windows. In mild weather the room thermostat will encourage the heating system to compensate for excess ventilation. The occupier may not realise the energy penalty of this action. Dick & Thomas [10] revealed the British tendency to open the windows in mild weather, fig. 3. Re-analysis of field data of central heating trials in 1968/69 at Bromley, London, showed a similar pattern. [11] However the re-analysis was crude and served only to underline the need to identify user behaviour. The subsequent surveys of two housing estates showed a remarkable pattern, fig. 4. This pattern was influenced by the number in the family. The average winter window opening was crudely proportional to the actual number in the house. When asked why they opened the windows the biggest proportion, 68% said to freshen the house and the second reason was to avoid condensation, 31%.[12]

The next research step is to investigate electrical opportunities which will remove the occupier's incentive to over-ventilate.

4. ODOUR CONTROL

Research has concentrated on identifying the malodorants in cooking smells, particularly those in boiling cabbage, and body odours, particularly those related to perspiration. Over thirty individual compounds have been identified while cooking cabbage and their relative concentrations measured. The ten highest levels of concentration are given in Table I alongside the mean odour threshold for each compound. The ratio of concentration to odour threshold is an index of smell strength. Such analysis identifies dimethyl sulphide as the dominant compound accounting for more than 80% of the perceived smell. Many obnoxious smells are compounded from a limited number of malodorous chemicals. Analysis of body odours revealed two types of malodorants namely the organic sulphides and the aliphatic amines. These are also present in the cabbage and the fish smells of cooking.

The domestic environment is likely to contain organic sulphur compounds such as sulphides and mercaptans, and nitrogen containing compounds such as ammonia and amines with low molecular weight. Carboxylic acids, aldehydes, ketones and alcohols are present to a lesser degree.

Two common techniques to eliminate odours are absorption and oxidation. Absorption in charcoal beds is not effective for all compounds and suffers from a limited capacity. It is also affected by water. The most effective method is oxidation by means of ozone and photoxidation by ultraviolet light. Both processes can be achieved using a suitably modified low pressure mercury lamp. The sulphur and nitrogen containing compounds should be readily oxidised by this method. The carboxylic acid and higher molecular weight compounds will be less readily affected.

Two types of experiment have been undertaken. The first studied the rate of decay of the malodorant in a static system. The reactant, a single compound, was mixed with ozone in a ten litre plastic vessel. Ozone was fed into the vessel at a constant rate to produce about 5 p.p.m. The rate of decay of the malodorant was measured using gas chromatography. This was done at rather higher levels of concentration than expected in a house because the measurement equipment is not as sensitive as the nose.

The effectiveness of destruction was assessed by computing the time taken for half of the malodorant to be decomposed. Faster reaction times occurred as the concentration of the malodorant decreased. The half life of dimethyl sulphide is given in table II together with values extrapolated to 0.1 and 0.01 p.p.m. The shorter times at the lower concentrations show that dimethyl sulphide is destroyed more efficiently at lower concentrations. The half lives of a range of sulphur containing compounds when exposed to ozone are given in table III. The higher sulphides and disulphides react more quickly than carbon disulphide and the mercaptans. Increasing the relative humidity of the air from 15 to 100% increased the reaction rate between ozone and dimethyl sulphide and dimethyl disulphide.

The second type of experiment involved a flowing not a static gas mixture. The malodorant, suitably diluted in air was mixed with ozone formed by the irradiation of air by a low pressure mercury lamp. The decomposition of the malodorant and of the ozone was measured downstream of the lamp. Reaction rates agreed with those found in the static experiment. However if the malodorant/ozone mixture was irradiated while reacting the rates of destruction were increased by up to two orders of magnitude. This phenomenon is under investigation. It presumably depends on the products of irradiation of ozone being more effective than ozone itself.

5. MOISTURE REMOVAL

The two complementary routes for moisture control are reduction in the release rate at source and extraction from the areas at risk. Fournol [13] estimated 10-40kg of moisture released per day in French flats. Loudon [14] calculated a moisture release of 7kg per normal day of which 3kg were from cooking. On washday the moisture from clothes drying would increase the total value to 15kg/day. This means that the two major sources of moisture are cooking and clothes drying. Ventilation extract from the kitchen should be via a cooker hood. Clothes drying should be vented to the outside.

The second route is moisture extraction. This is most effectively achieved by a heat pump dehumidifier. The evaporator chills the incoming air which deposits moisture on the heat transfer surfaces. The water then drains to a collecting tank. The cold, drier air is then blown over the condenser and is reheated. The reheat comprises the refrigerant compressor power together with the sensible and latent heat collected from the evaporator. Laboratory measurements show a water extraction characteristic which increases with the relative humidity and with the temperature of the incoming air, fig. 5. Specific energy consumptions of water extracted per kWh vary with the ambient conditions. At ordinary room temperatures the effectiveness lies between 0.5-1.0 kg water extracted/kWh. The latent heat addition means that for every electrical kWh expended there will be an extra 0.7-1.4 kWh released into the room.

The heat pump dehumidifier has a double benefit. It saves the high ventilation heat loss which would otherwise be necessary. It also translates the latent heat of the troublesome water vapour into sensible heat which can be useful.

6. CONCLUSIONS

Ventilation is rapidly becoming the major factor influencing space heating energy consumption. This is both in terms of the minimum design ventilation aimed to reduce body odours and also the user behaviour pattern over the heating season. A contributing factor for the occupants' habits is the risk of condensation.

Two electrical solutions are proposed to meet the occupants' requirements. The first is a combined ozone/ultraviolet irradiation technique which is particularly successful at oxidising low concentration malodours into harmless inoffensive compounds. The second is the heat pump dehumidifier which not only removes the need for high ventilation rates but also recovers the latent heat of the water vapour.

7. ACKNOWLEDGEMENTS

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Table I Cabbage Volatiles

Compound	% by volume	Mean odour threshold p.p.m.	Perceived level of smell	
			Concentration odour threshold	% of total
dimethyl sulphide	26-34	0.01	3000	83
acetone	11-14	253	0.05	0.01
methyl alcohol	12	100	0.12	0.003
allyl isothiocyanate	6	0.2	30	0.8
diethylketone + diacetyl	5-6	0.1	55	1.5
cishex-3-en-1-ol	4-4.5	0.07	61	1.7
acetaldehyde	3.5-5.0	0.01	430	12
ethyl alcohol	3.5-5.0	10	0.38	0.01
allyl cyanide	3	0.1	30	0.8

Table II Half life ($t_{\frac{1}{2}}$) of dimethyl sulphide versus concentration

Ozone concentration ~5 p.p.m.

initial dimethyl sulphide concentration in p.p.m.	$t_{\frac{1}{2}}$ in min.
1500	29.3 ± 0.2
30.5	8.0 ± 0.9
3.05	4.7 ± 0.2
0.1	1.6*
0.01	0.8*

*values extrapolated using the relationship $t_{\frac{1}{2}} \propto [\text{dimethyl sulphide}]^{0.3}$

Table III Half lives of sulphur containing compounds

Ozone concentration ~5 p.p.m.

Compound	initial conc. p.p.m.	$t_{\frac{1}{2}}$ in min.
dimethyl sulphide	30	8.0 ± 0.9
dimethyl disulphide	25	3.8 ± 0.6
diethyl sulphide	21	6.6 ± 0.6
carbon disulphide	37	13
methyl mercaptan	40	14

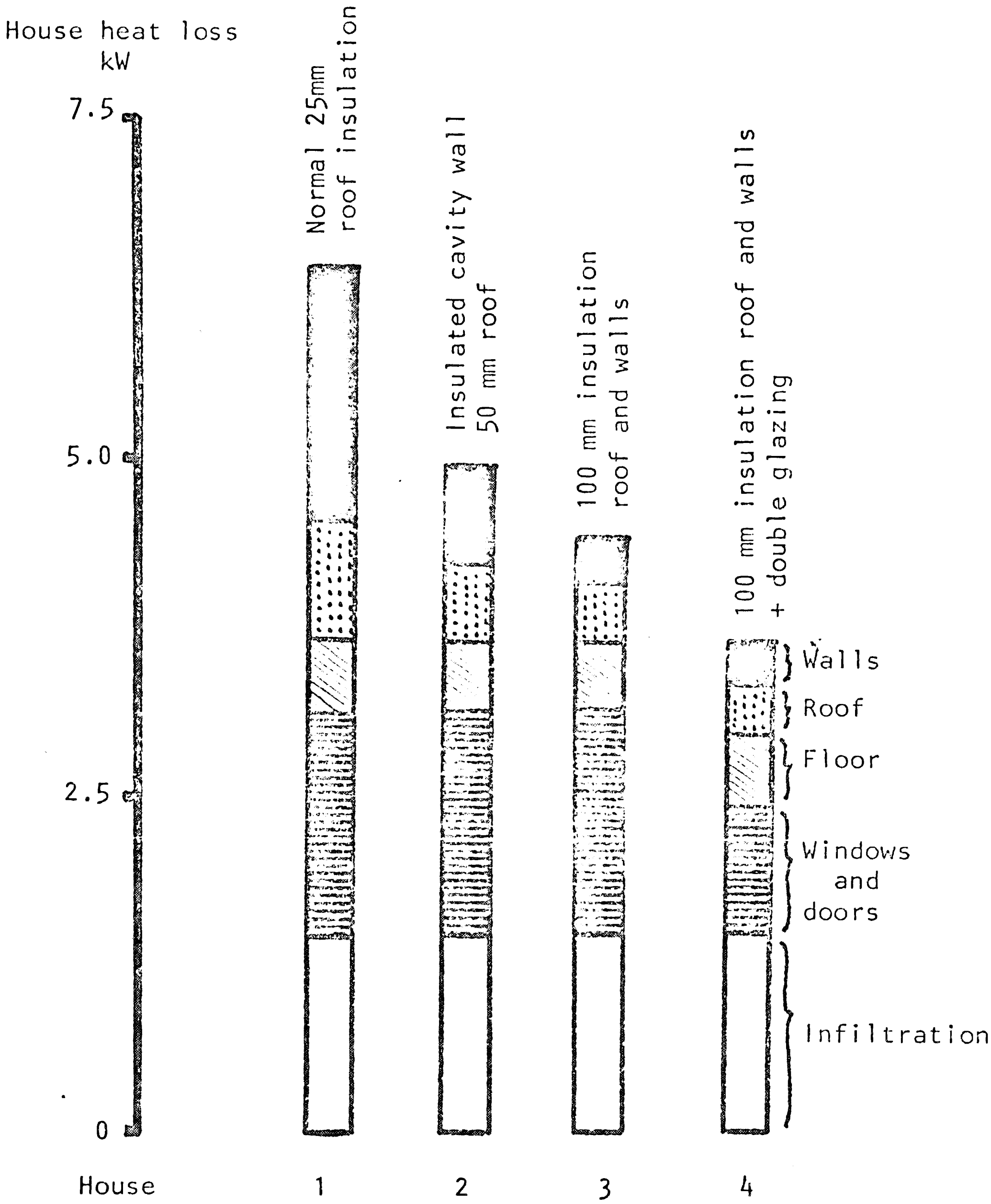

Fig. 1 Design heat loss for a British house
($90m^2$ semi-detached two floors $220m^3$)

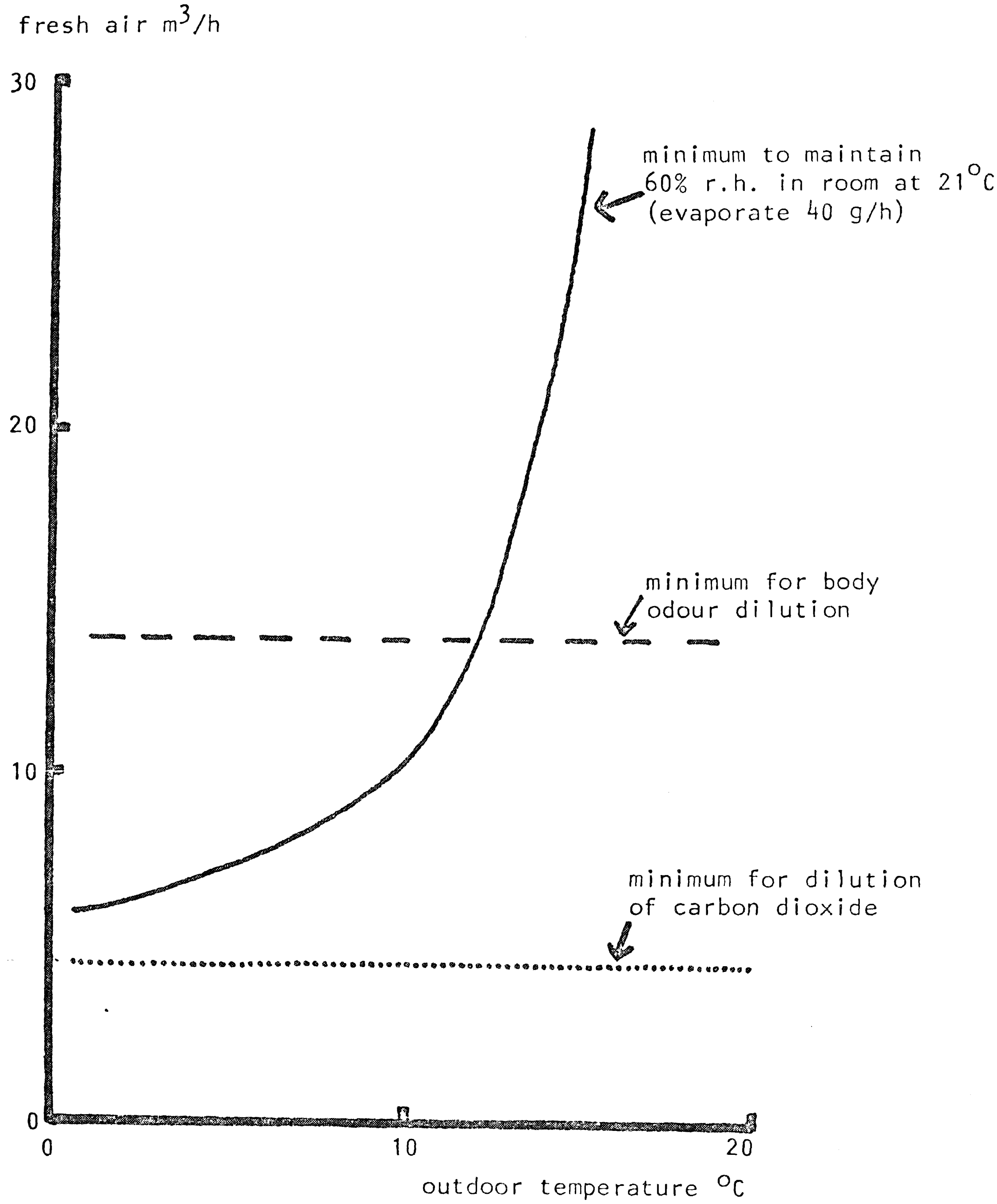

Fig. 2 Ventilation needs of an adult in Britain

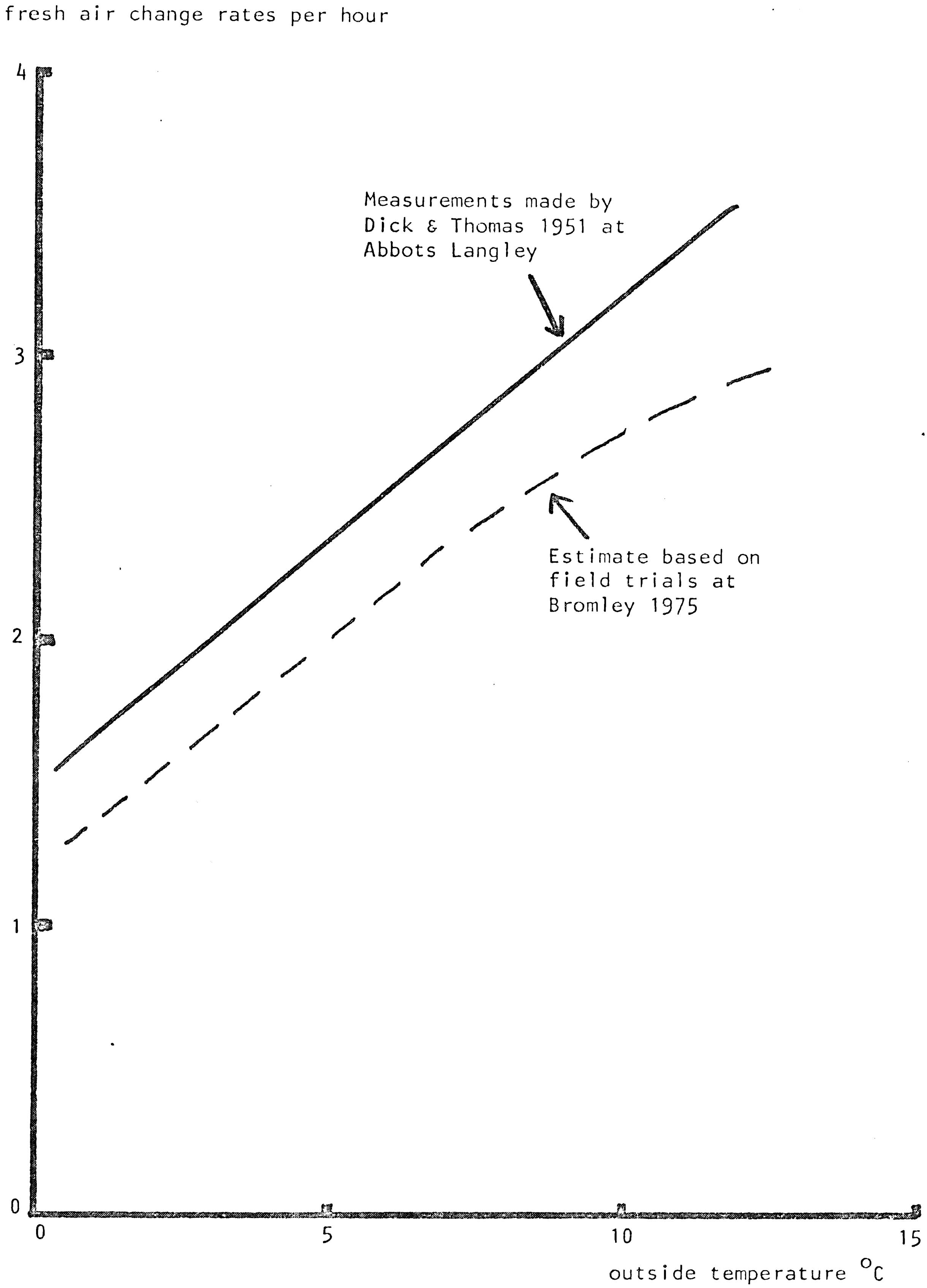

Fig. 3 Seasonal relationship between fresh air and outside temperature

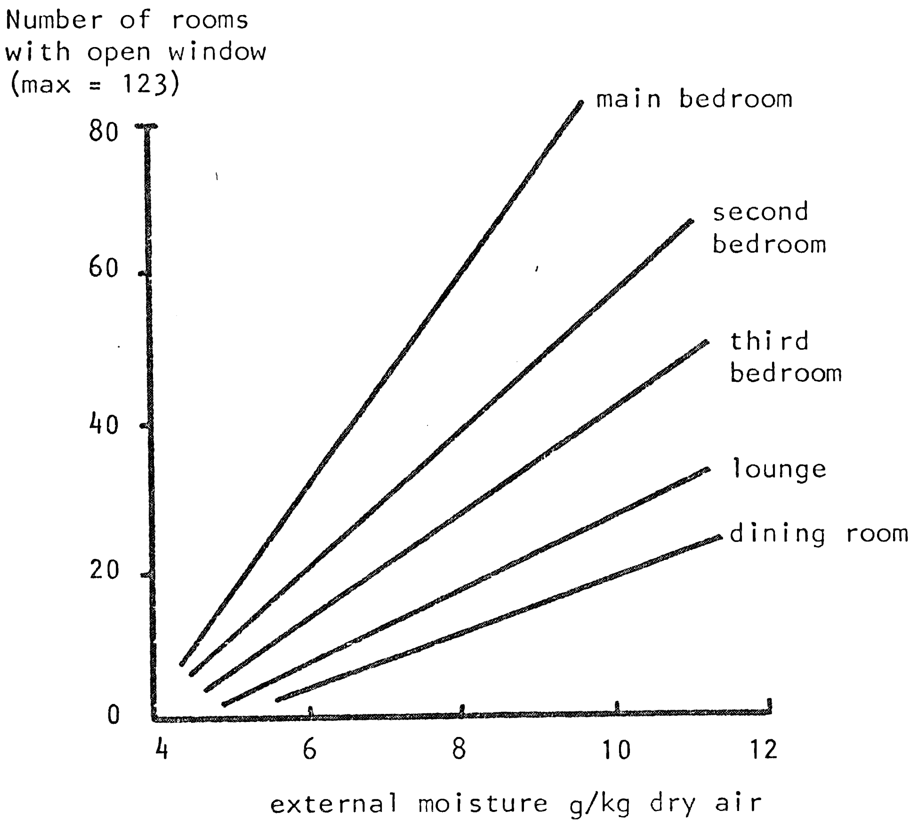

Fig. 4 Relationship between windows open and external moisture

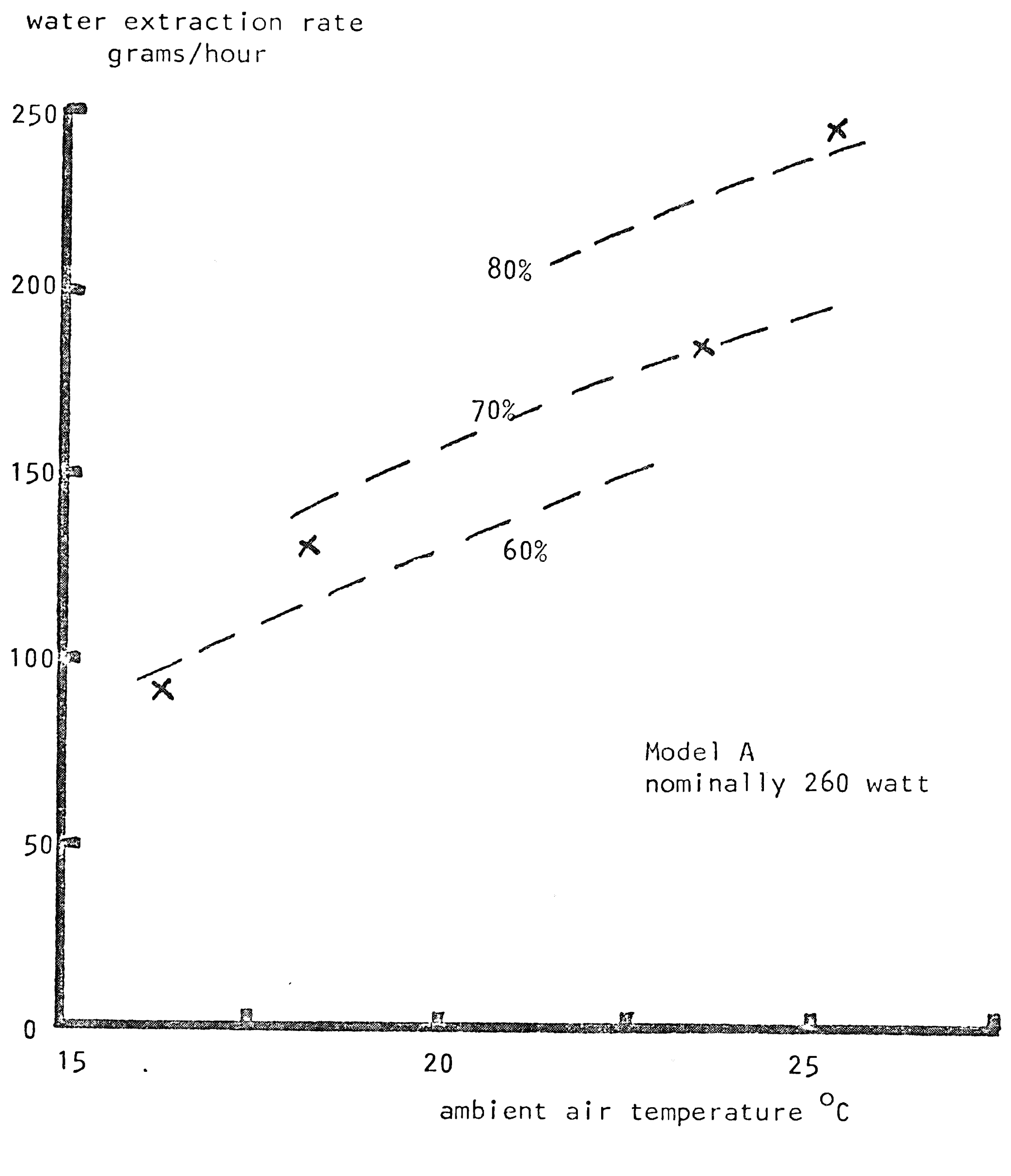

Fig. 5 Water extraction performance of domestic dehumidifier