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"DEHUMIDIFICATION TECHNOLOGY"

A PAPER PRESENTED AT THE 1988 COMBATING CONDENSATION SYMPOSIUM

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1. Background

The early dehumidifiers were essentially ice-making equipment applied to chilling and dehumidifying air. Ice had long been used for food preservation and the biggest market for the new refrigeration industry was to produce artificial ice throughout the year. This machinery was developed towards the end of the nineteenth century.

The applications for dehumidification were large scale ones to match the scale of the equipment. The first uses were storage of photographic film (1891) and for storage and horticulture (1894). The incentive to produce controlled humidity was provided by the practicality of colour printing. Colour printing machinery relies on precision location of the paper within each colour machine so that the required colours superimpose themselves without blurring the edges of the picture. It was soon recognised that the dimensional stability of the paper was a critical factor. The shape, pliability, and size of paper changes with ambient relative humidity. Constant relative humidity is, therefore, essential for consistent colour printing. Willis Carrier produced the design for such an air treatment plant in Brooklyn in 1902.

Other specialist applications developed. Moisture removal from blast furnaces, and gas liquefaction, controlled moisture in the tobacco, textile and food idustries. By the 1920's the large refrigeration equipment was being used not only in industry but in theatres, offices and shops for comfort cooling. However, developments in refrigerants and compressors and particularly the concept of small hermetically sealed refrigeration circuits introduced by General Electric in 1926, led to the growth of the domestic refrigerator market. By 1931 there was a range of small dehumidifiers on sale in the United States in sizes from 1.3 to 3 h/p. These were used for the prevention of dampness in pipe organ lofts to retain their tuning, to keep the developing telephone exchanges dry and therefore minimise corrosion and electrical short circuits, and to protect goods in storage and on display in museums. Slowly the dehumidifier became recognised as an essential device to keep the cool house basement dry in summer.

In 1947 the manufacture of dehumidifiers was achieved by the newly developed mass production process and by 1952 some twenty-eight U.S. manufacturers together produced over 75,000 units/year. Japan followed and today both Japan and the United States each make over a million units annually. Britain started serious manufacture of small dehumidifiers in 1980 and by 1983 had six manufacturers. In 1987 sales are over 50,000/ year and rising. Selling outlets have extended from the specialist shops dealing with serious problems, through the door to door commissioned salesmen, into the low overhead appliance showrooms of Electricity Boards and other multiple stores.

The benefit of the high volume sales has led to a price reduction of 30% over five years and the introduction of a high technology unit with half the running cost of traditional equipment.

2. Operating principle

There are two basic methods of dehumidification. The simplest is by condensation onto a cold surface. The alternative is to use a liquid or solid sorbent. Silica gel is the most popular solid sorbent. In practice, the sorbents are used at temperatures below freezing while the chilling principle is used for temperatures from 5°C to special equipment at 100°C.

The most common domestic dehumidifier is based on a refrigerant circuit with six components: the compressor, the condenser, the expansion valve, the evaporator, the refrigerant fluid, and the fan for recirculating the air. This is illustrated in Fig.1.

The refrigerant cycle works in this way. The compressor draws the refrigerant from the lower pressure evaporator and introduces it into the condenser at a higher pressure. Both the evaporation and condensation of refrigerant occur at relatively constant temperatures and pressures. The evaporation process requires latent heat. This heat comes from the mass of air being drawn over the outer surfaces of the evaporator which then cools. When the evaporator surface falls below the dew point of the air then condensation occurs on the evaporator and dehumidification starts.

The refrigerant leaves the compressor hotter and at higher pressure and condenses in the condenser. A typical compression ratio is 5 to 1. The latent heat of condensation released warms up the ambient air passing through the condenser. The liquid refrigerant is then reduced back to a lower pressure through the expansion valve and evaporates in the evaporator.

The damp air is drawn through the evaporator and condensation of water occurs on the cold surface. This cold but dryer air is then drawn over the condenser where it is reheated and receives the energy from both the compressor and from the sensible and latent heat of the cooled air stream over the evaporator.

The refrigerant cycle is illustrated in Fig. 2.

This is the basic design of a refrigerant dehumidifier. It is deceptively simple because, as in all refrigerant cycles, any change in one component has an effect on the performance of all the other components. This strong interaction means that iterative design procedures are necessary. Fortunately, there are now computerised design algorithms which can rapidly establish trend lines of performance and can readily be used for sensitivity analyses.

The water extraction rate for a given dehumidifier is influenced by both the room temperature and relative humidity. Higher humidities and higher temperatures lead to higher moisture extraction rates. The more important factor is the relative humidity. At 10°C the moisture extraction rate is increased by a factor of five when the ambient relative humidity increases from 30% to 100%. The electricity consumption also increases with increasing temperature and humidity. This is illustrated in Fig. 3. At low room temperatures the evaporator temperature falls below freezing point and the condensate appears as ice. If left undisturbed this would eventually block the air passage and dehumidification would cease. Provision is therefore made on most models for a defrost cycle to be initiated regularly under such conditions. At its simplest this is a time clock which opens a solenoid valve to enable the compressor to discharge hot gas directly into the evaporator.

The effectiveness of water extraction can be improved by incorporating an air to air heat exchanger in the circuit. This is illustrated in Fig. 4. The incoming air to the dehumidifier first passes through the cold air to air heat exchanger. This cools the air to below dew point and the first stage of dehumidification occurs within the heat exchanger. The cool saturated air then reaches the evaporator and the conventional dehumidification occurs. The cold, less moist air is then returned on the other side of the air to air heat exchanger to chill the incoming air. This additional air to air heat exchanger has two important advantages. The first is to double the effectiveness of the dehumidifer. The second is to make the dehumidifier performance much less sensitive to ambient relative humidity because the evaporator always sees air which is close to saturation. One British manufacturing company now produces a dehumidifier based on this concept. The relative performance of it compared with a conventional dehumidifier is illustrated in Fig. 5.

Further developments include new rotary and scroll compressors which are smaller, lighter and even more reliable than the present range of already reliable compressors. Variable speed drives permit optimum temperature and air flow. New refrigerants do not boil at constant temperature and have advantages in such applications.

3. <u>Application to housing</u>

Dampness is Britain's major housing problem, seriously affecting two million homes and even larger numbers less seriously. Approximately two-thirds of this problem is attributed to condensation inside the house. The results of a random survey of 7,000 houses is illustrated in Table I.

More detailed analyses from a local authority survey in Newcastle of over 600 dwellings confirmed the general order of magnitude. Some 30% experienced dampness. Private rented unfurnished accommodation had the highest incidence (4 9%) while only 14% of owner occupied dwellings reported it. Bedrooms were most affected (45%), kitchens less so (26%), with living rooms and bathrooms noted in only 16% of the reports.

Three major factors influencing dampness came from the Newcastle survey, namely thermal insulation, degree of exposure and family size. Condensation problems were the highest in the poorly insulated dwellings. Detached and end terrace dwellings were more affected by damp than mid terraced housing of the same construction. The incidence of dampness increased rapidly with increasing family size (Fig. 6).

Research into quantifying the moisture generated within a house is rare but considered estimates suggest approximately equal amounts from the occupants and from cooking. This, together with the more modest amount released from bathing, dishwashing and washing, totals just over seven litres each day. This quantity is almost doubled on those days when clothes washing and drying take place within the home. The best estimates of moisture generation are summarised in Table II. These values are in good agreement with quantities measured subsequently in four highly insulated houses which incorporated planned mechanical ventilation.

Housing in Britain is a particularly good application for dehumidifiers. Our cool, damp climate and our reluctance, or inability, to provide a warm building means that dampness affects approximately thirty per cent of our total housing stock. We know that condensation problems are the worst in more crowded dwellings, in dwellings which are exposed and in those built with poor thermal insulation. We know that the coldest rooms are the most affected and that these are often the bedrooms. We even know the approximate amount of moisture released each day in a house.

The dehumidifier not only removes the water from the atmosphere but it converts the latent heat of condensation into sensible heat which becomes available to warm up the outgoing air. More sensible heat is therefore supplied to the airstream than would be available simply from the electrical consumption of the device. The dehumidifier behaves as a small heat pump with a coefficient of performance (CoP) which varies directly with its water extraction rate. In saturated atmospheres a conventional domestic dehumidifier would have a CoP of 1.5. This would fall to 1.2 or 1.3 in drier conditions or 40% r.h. The advanced dehumidifier with the air/air heat exchanger has a significantly higher CoP and can achieve 1.5 at 65% r.h.

The selection of a suitable dehumidifier depends upon the particular conditions of each dwelling and its occupants. General guidelines are summarised in Table III.

The market potential for a device which eliminates dampness, while providing more heat than electricity consumed, is at least two million dwellings which already exist in Britain.

4. Field Trials

Two types of field surveys have been undertaken. The first was a market research appraisal of how purchases with a year or more experience viewed their dehumidifiers. The second was a monitored study of the installation of dehumidifiers in a group of local authority housing in Scotland. The first study was by the Electricity Council in conjunction with Doulton Wallguard Ltd.; the second by the Electricity Council in conjunction with the Building Research Station (Scotland) and tenants of the Inverclyde District Council with full cooperation and support from council members.

The first study was based on one hundred and fifty purchasers of dehumidifiers and 82 of them took part in the postal questionnaire. Dampness, mould or condensation were the reasons why these people bought the dehumidifiers. Bedrooms were the most popular location for the units (32%), followed by hall, living room and kitchen. Over half of the households rarely, if ever, moved the dehumidifiers from room to room. Nuisance features of their dehumidifiers were, principally, the disturbance caused by their noise (55% of respondents), followed by 13% of the respondents who found the units difficult to move from place to place.

The degree of satisfaction with the performance of the units was among the highest ever recorded for a domestic appliance. Some 89% declared themselves to be either very or quite satisfied with their dehumidifiers.

The second study was an appraisal in thirty households of three different sizes of dehumidifiers. These thirty were selected from invitations to some 300 tenants who were asked if they would like to try out a small portable dehumidifier. Each family was supplied by the Electricity Council with a dehumidifier free of charge and the cost of electricity used by the dehumidifiers was reimbursed. The nominal moisture extraction rate of the dehumidifiers varied from 1 litre/24 hours to 4 litres/24 hours at 12°C.

Seven day thermohygrographs were placed throughout the dwellings to record typical temperature and moisture conditions for each dwelling before the dehumidifiers were installed. These control tests took three weeks. the results from this monitoring period enabled each household to be categorised in terms of moisture load. The thirty dehumidifiers were then allocated to the households in such a way that those with the larger moisture loads were given the more powerful dehumidifiers and the lowest had the smaller machines. Further intensive recordings were then made for the next five weeks. Weekly visits were made to each dwelling to collect the recorded data. The dehumidifiers themselves were equipped with time recorders to indicate duration of use. The tenants agreed to write down at what times of the day the dehumidifiers were switched on. They were also encouraged to measure the amount of water collected.

After three months' experience of the dehumidifiers the researchers interviewed each household using a questionnaire aid. This set out to elicit both the general habits of heating and water use and also their opinions about the dehumidifier which they had used.

The response to the questionnaire appraisal was almost identical to that of the first survey. Over 80% of the families believed that the dehumidifiers had helped to alleviate the condensation problems. Bedrooms were by far the most common site for the dehumidification (96%) and most did not move the units around. Overall satisfaction was high (> 80%).

The one complaint was that of noise. Over half (56%) found the dehumidifiers too noisy for continuous running. The operating pattern tended to be daytime operation in unoccupied rooms and for the dehumidifiers to be switched off when the families went to bed.

An illustration of the effect of the dehumidifier is given in Fig. 7. Hourly measurements of temperature and humidity are plotted for almost a week. The records show that the water pressure in the room fell immediately the dehumidifier operated. The records therefore can be clearly divided into room conditions when the dehumidifier operated and those when it was off. The critical relative humidity for the onset of damp and mould in 70%. Above this value mould and musty smells can be expected.

When the dehumidifier was off the relative humidity exceeded 70% for over half the time. When it was running the relative humidity dropped on average below 60%. This householder ran the dehumidifier for 13 hours each day and extracted 1.8 litres of water daily. The room temperature rose slightly when the dehumidifier was running (~ 2°C).

5. The Future

New products usually go through three phases. The first and most difficult stage is the creation of the market. This commercially hazardous phase

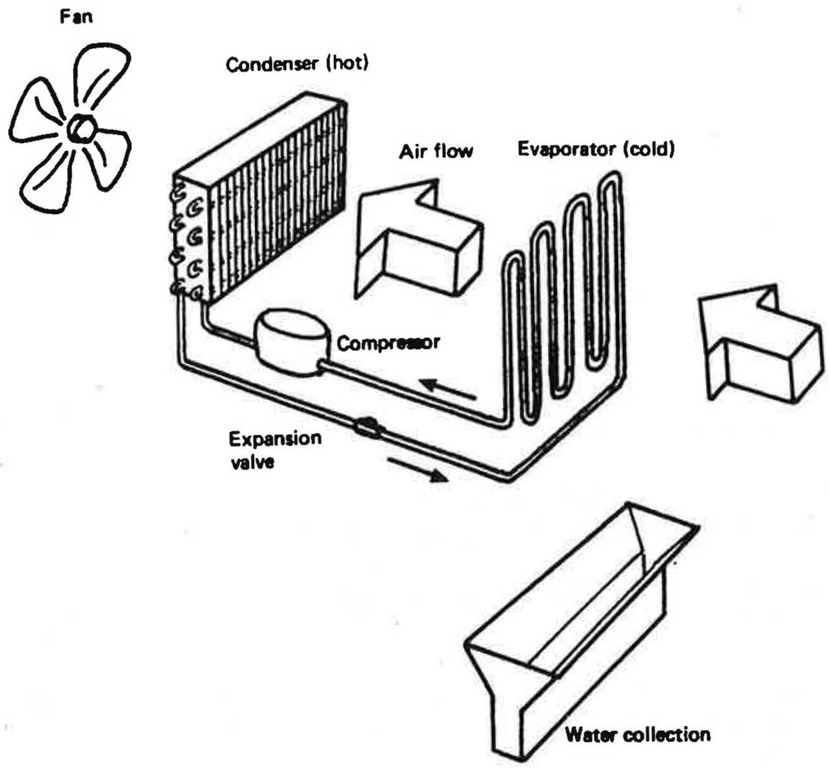

Figure 1. Components of a refrigerant type dehumidifier

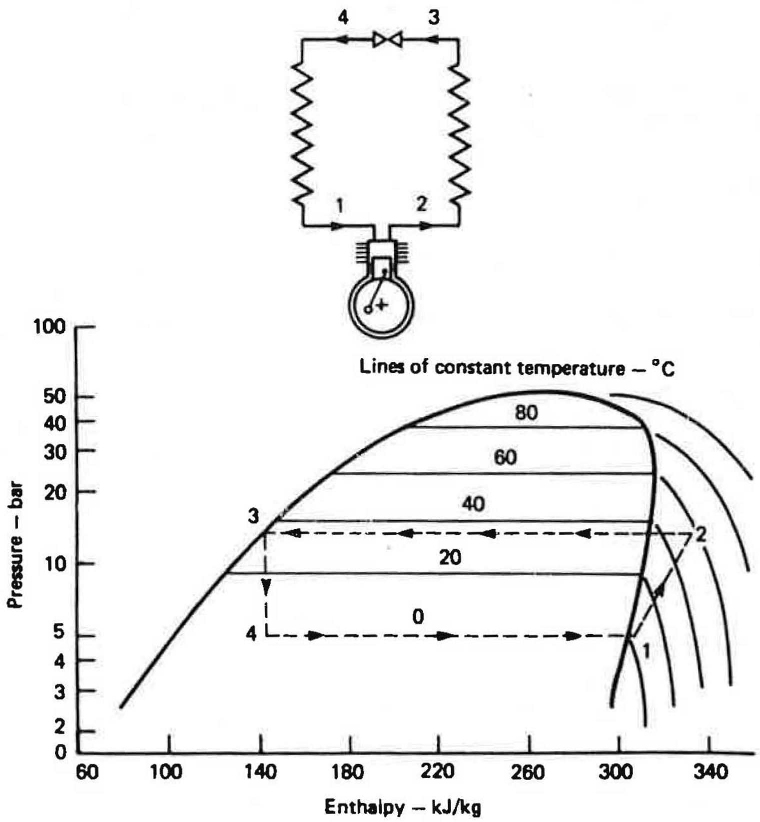

Figure 2. The refrigerant cycle for the dehumidifier

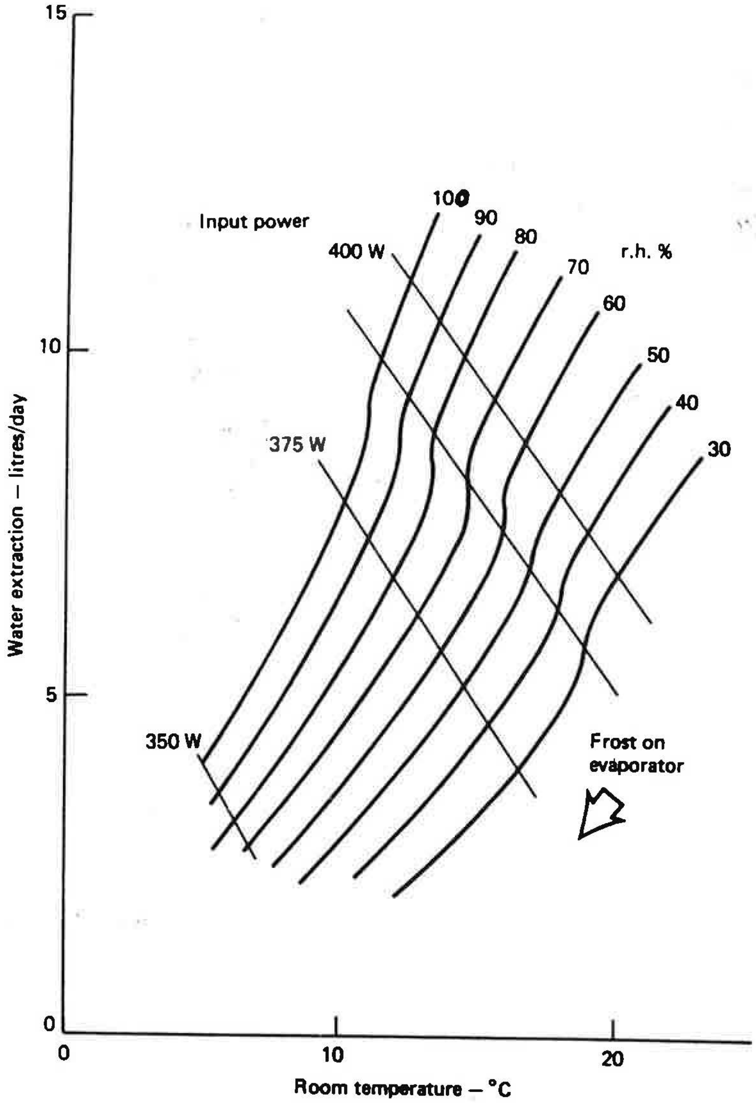

Figure 3. Illustrative performance of a large domestic dehumidifier

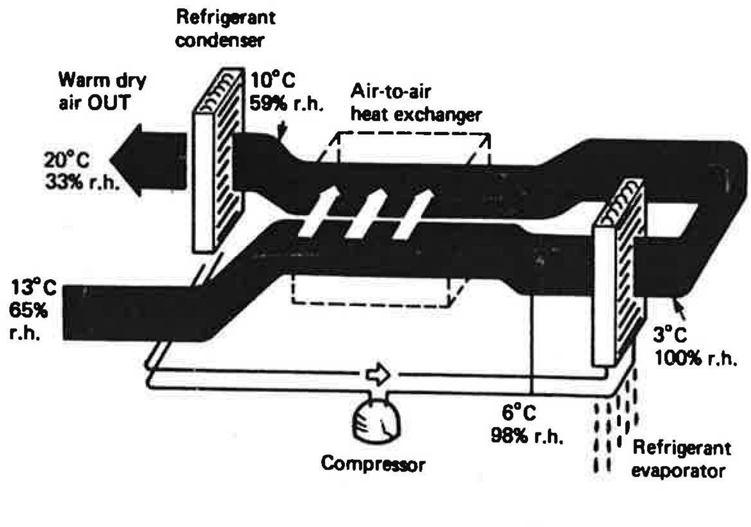

Figure 4. The incorporation of an air/air heat exchanger improves the effectiveness

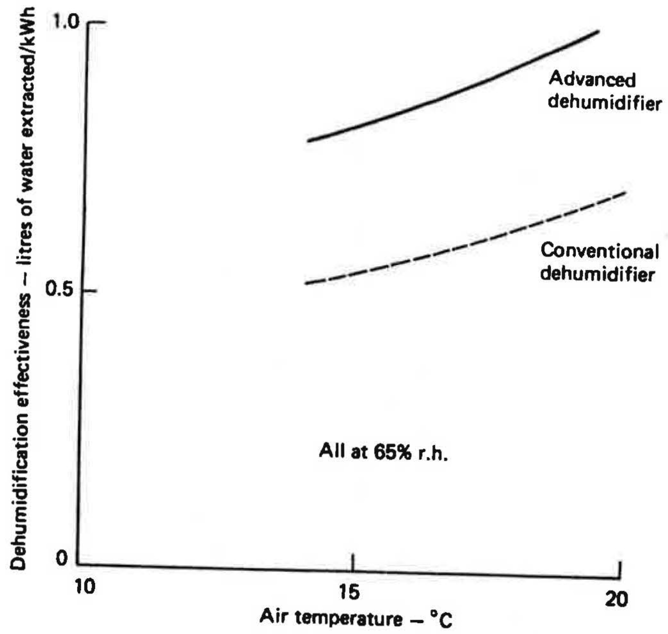

Figure 5. The effect of the air/air heat exchanger

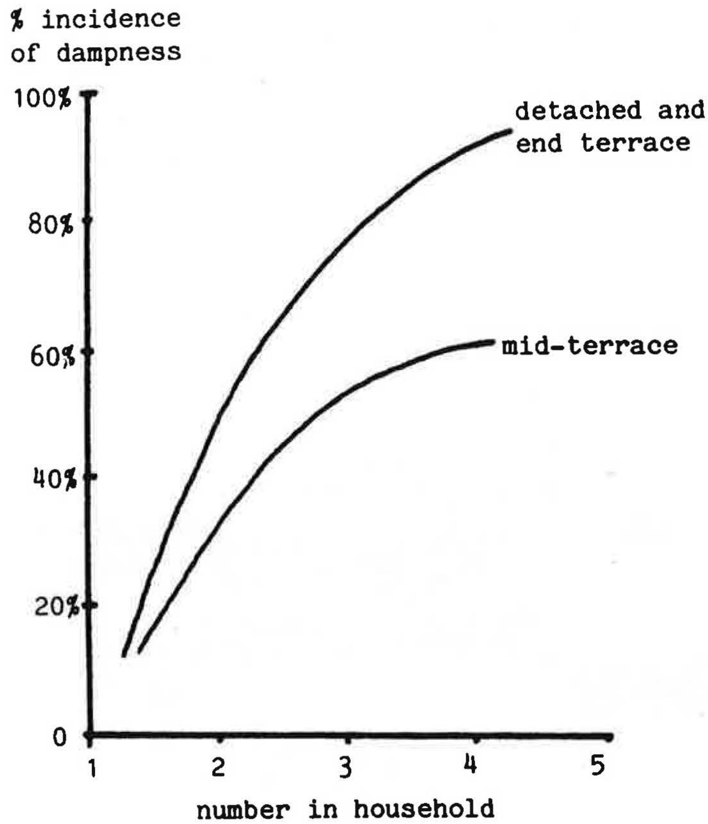

Figure 6. Dampness is influenced by family size and exposure

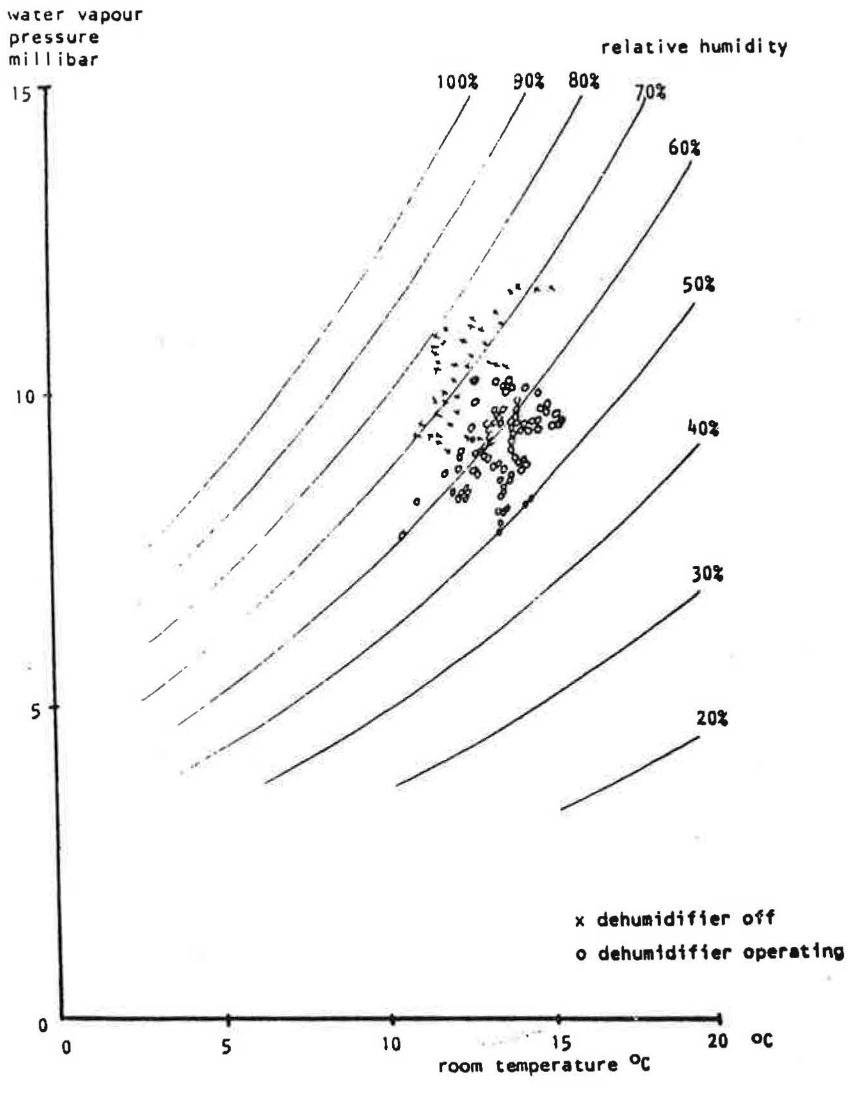

Figure 7. Influence of a dehumidifier in a warm room

TABLE I The incidence of dampness in housing

	Owner occupier million	Private rented million	Local authority million	Total million
Dry	7.7	1.3	3.5	12.5 (73%)
Slight damp	1.2	0.5	0.8	2.5 (15%)
Severe damp	0.4	0.7	0.9	2.0 (12%)
Total	9.3	2.5		17 (100%)

(Cornish 1983)

TABLE II Moisture generated in the home (five person family)

Breath and perspiration	3.2 litres
Cooking	3.0 litres
Bathing, dishwashing, washing	1.0 litre
	7.2 litres
Additional sources	
Clothes washing	0.5 litres
Clothes drying	5.0 litres
Paraffin heater	1.7 litres
	7.2 litres

BS 5250 : 1975

TABLE III Checklist for selection

1. Portable or fixed machinery? Portables come with a bucket which needs regular emptying. The fixed machines are designed for wall mounting and require a drain.

2. Air flow? Aim for one recirculation air change per hour in the room.

3. Water extraction rate? Allow 1 litre/person/day at 10°C 70% r.h.

4. Defrost? A defrost cycle is usually required for use in British houses.

5. Humidistat? A useful feature particularly on the more powerful dehumidifiers 350w.

6. Location? As close as practicable to the dampness problem. This usually means just outside the bedroom door so that there is no noise disturbance.

TABLE IV Survey or private purchasers of dehumidifiers (N=82)

Average Family size		3 people
Reason for purchase	condensation problems	61%
	damp	27%
	condensation and damp	7%
	mould and mildew	5%
		100%
Rooms in which used	bedroom	32%
	hall	23%
	living room	14%
	kitchen	11%
	landing	10%
	other	10%
		100%
Is it moved around	moved a lot	13%
	occasionally	31%
	hardly ever	36%
	never	20%
		100%
Bad features	noise level	55%
	difficult to move	13%
Frequency of emptying bucket	twice a day	4%
	daily	23%
	every 2-3 days	13%
	every 3-5 days 17%	19%
	weekly	19%
	fortnightly	5%
	monthly	2%
Satisfaction	very satisfied	47%
	quite satisfied	42%
	not sure	3%
	not very satisfied	7%
	not at all satisfied	1%
		100%