An advanced dehumidifier for Britain

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Introduction

Condensation is Britain's major problem in buildings. In houses it can lead to unpleasant sultriness, mould growth and a thriving population of house mites (1). It can also induce deterioration of the building fabric itself. In factories and warehouses it can accelerate corrosion and spoil packaged goods. The cause is Britain's mild, damp winter, when outdoor air conditions are only just below saturation vapour pressure (2) (figure 1). Fortunately, this high relative humidity does not extend to summer. The moisture problems are therefore generally restricted to winter when space heating is also required.

Present practice to control moisture is a combination of heating and fresh air ventilation. Kitchens are ventilated to remove steam and open windows freshen the house. Factory plant engineers keep the space heating on at night to prevent excessive drop in temperature and the associated rise in relative humidity, which would increase the risk of condensation droplets and consequent rust spots on the part-finished goods. Moisture control is therefore crudely achieved with a high ventilation rate and/or high temperatures, and correspondingly high energy losses (3, 4). Increased fabric insulation makes the ventilation loss proportionately more significant and increasing energy costs encourage appraisals of less extravagant methods of moisture control.

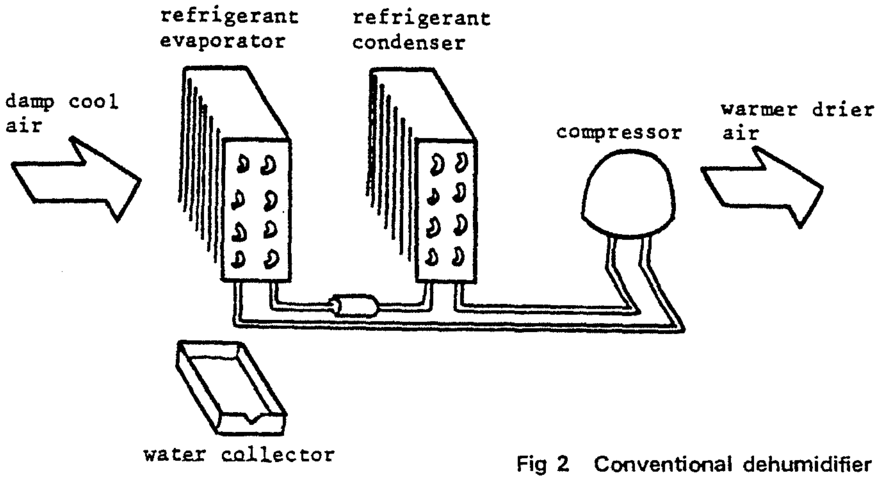


Fig 2 Conventional dehumidifier

The heat pump dehumidifier

Small, low cost, free standing, heat pump dehumidifiers (~300W) are now in widespread use in homes in the United States and Japan. Their major application is in summer when the climate can be warm and oppressively humid. A machine which removes moisture, even at the risk of increasing air dry bulb temperature, is attractive.

The cycle functions by drawing humid air over the evaporator coil and chilling it. If the coil temperature is below the air dew point then moisture is precipitated on the heat transfer surface and drained. The cool, now drier air, passes immediately through the hot refrigerant condenser coil and is reheated. The reheated air then returns to the room both drier and warmer than the incoming air (figure 2).

Such machines work well in warm, humid conditions but their performance falls at lower temperatures (figure 3). However, the principle of

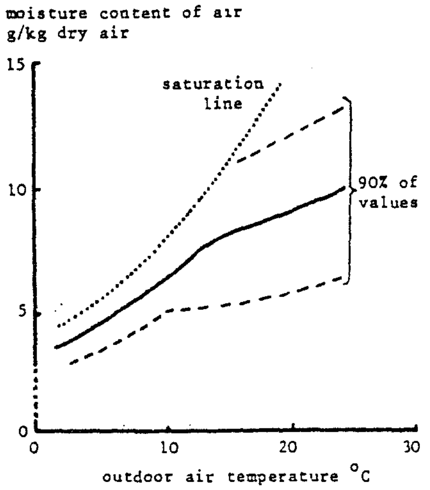
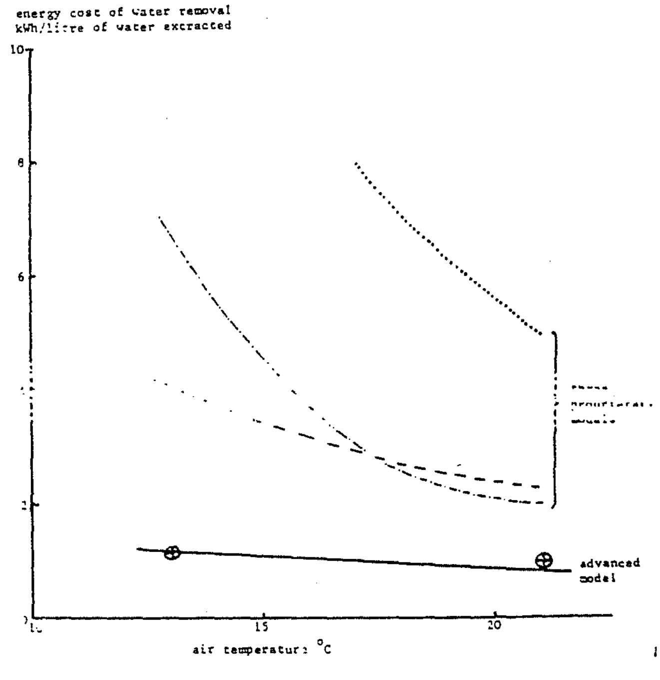


Fig 1 Britain's weather in terms of humidity

Fig 3 Energy cost of moisture extraction at 50% rh



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removing moisture and providing some air heating is exactly what is needed for Britain's buildings in winter. The heat output from such a machine is more than its electrical consumption because it converts the latent heat of the problem moisture into sensible heat. Development of a dehumidifier more closely matched to Britain's need was therefore a major target for the Electricity Council Research Centre (5).

The advanced dehumidifier

In the conventional dehumidifier (figure 2) the refrigerant circulating through the evaporator coil has first to cool the air down to its dew point. Little water is extracted during this stage. The air is subsequently cooled further and a greater quantity of water is then extracted. The air is finally reheated by the condensing refrigerant. A significant proportion of this cooling and reheating can be done more simply and effectively by counterflow heat exchange (figures 4 and 5). This means that the evaporator now receives saturated air and hence can extract more water for the same amount of refrigerant circulation. The overall effectiveness of the new cycle depends upon the matching of the counterflow heat exchanger with the compressor and the associated refrigerant circuit. Low cost digital computation now enables such complex design appraisals to be feasible.

An iterative computer model of the cycle was constructed to evaluate the sensitivity of the design to the engineering parameters (6, 7, 8, 9). This mathematical model accepts the manufacturer's performance characteristics of a compressor. It includes simultaneous heat and mass transfer across both the evaporator and the inlet side of the air to air heat exchanger. The evaporator and condenser are assumed to be fin and tube heat exchangers of the conventional refrigeration type and appropriate correlations used. The air to air heat exchanger is modelled as a static plate and fin heat exchanger. The pressure drop of the air stream is calculated from friction factor correlations. The fan power is then computed from this pressure drop, assuming an impeller efficiency of 40% and an efficient motor. Simplifications included neglecting variations in superheat of the suction gas and sub-cooling of the liquid line. Also excluded were entry and exit pressure losses at the heat exchanger.

The operation of the three heat exchangers and the compressor is inter-active. The model logic therefore proceeds iteratively, starting from estimated temperatures, calculating compressor performance and then using this to predict temperatures which are then compared with the estimates. The calculation cycle repeats itself until the whole cycle balances in terms of temperatures and heat flows (figure 6).

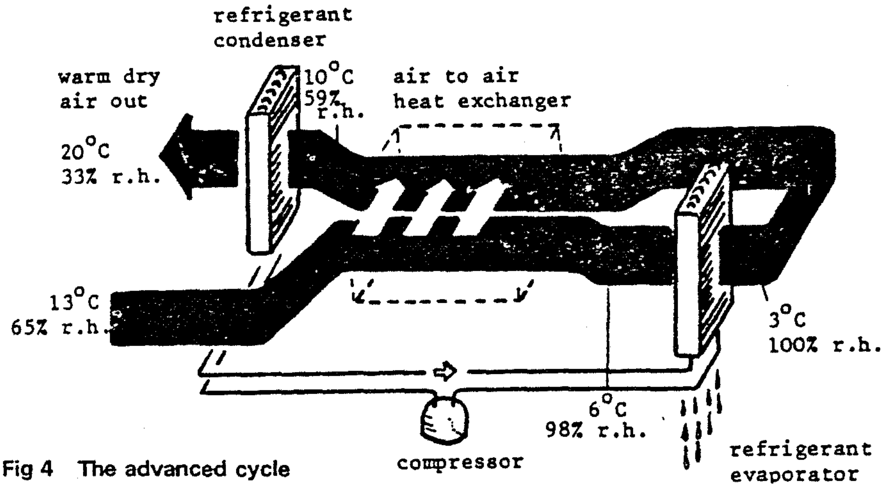

Fig 4 The advanced cycle

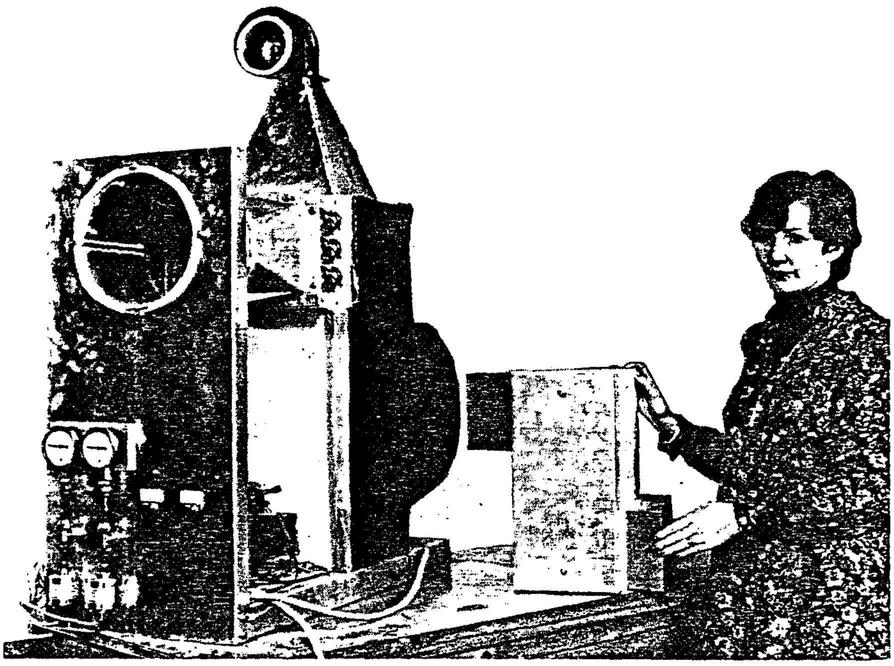

Fig 5 Prototype advanced humidifier, lab unit on left, commercial mock-up on right

Design details

This design procedure was applied to a domestic dehumidifier, sized to extract at least half of the 7 litres moisture generated inside a typical family house each day (4). The compressor selected was a popular 130W 3.3 cm displacement hermetic unit using refrigerant R12.

Details of a suitable design are given in figure 4. Air input conditions assumed are the typical winter bedroom conditions of 13°C 65% rh, and the rate is taken as 0.03 m^3/s (~$108m^3/h$ or approximately one air change per hour for the total upstairs volume of a house). In steady state conditions and with an electricity consumption of 24W for the fan and 120W for the compressor, the air will be returned to the room at 20°C and 32% rh. Almost five litres of water would be extracted during the day.

The addition of this air/air counterflow heat exchanger to a conventional dehumidifier improves its effectiveness by at least 100% in warm and high relative humidity conditions and by almost ten times at low temperatures and 50% rh.

Furthermore, the moisture extraction capability for a given compressor size can be trebled.

The high effectiveness of moisture extraction now means that the unit can be seriously considered as a heat pump for background heating. The ratio of heat out to electrical energy input is termed the coefficient of performance. In typical bedroom conditions in Britain the COP is now over 2.0 and exceeds 2.5 in high humidity conditions. This means that for every 100W of electricity, over 200W of heating will be supplied (figure 7).

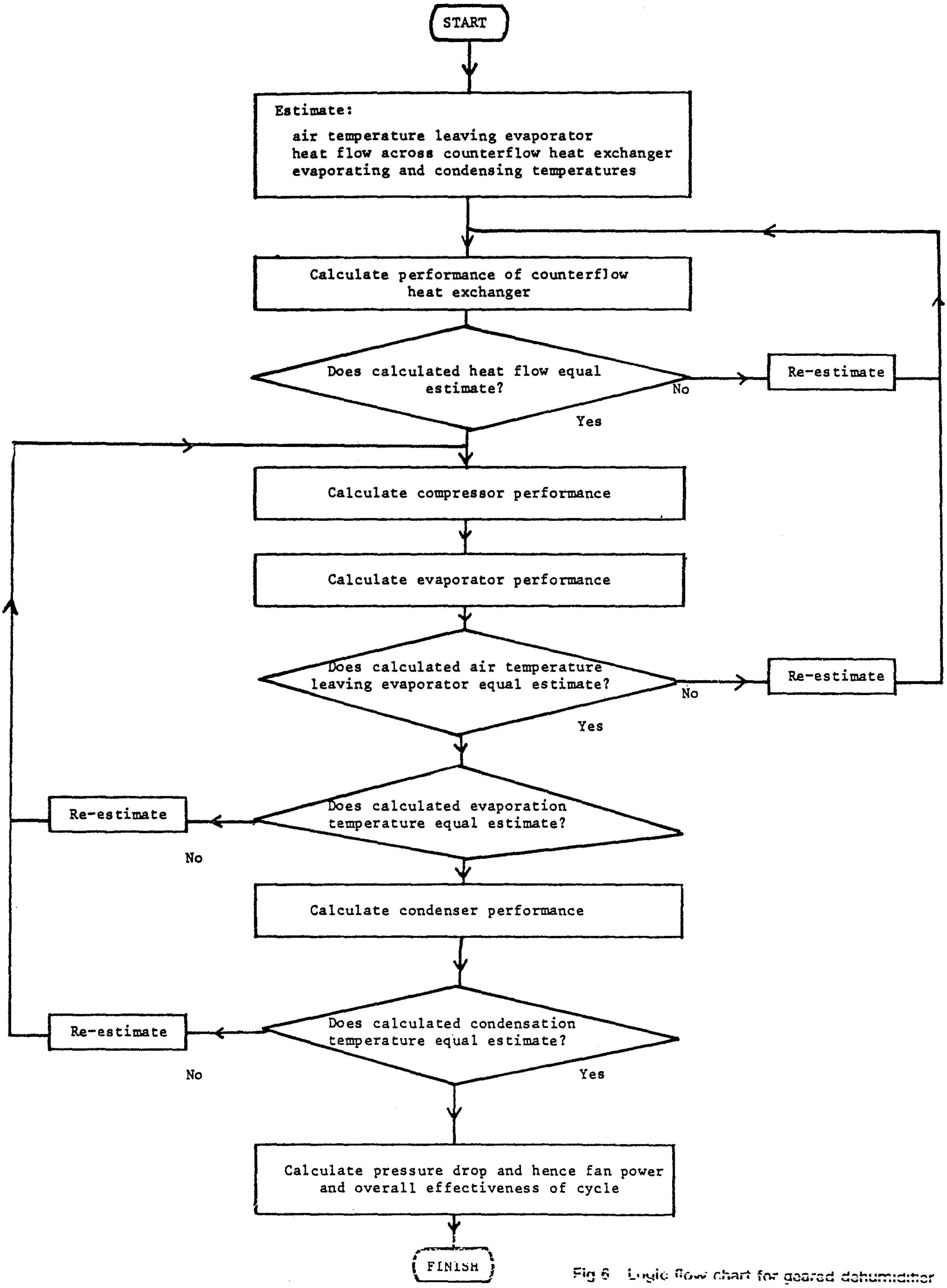

Fig 6 Logic flow chart for geared dehumidifier

Experimental verification

A prototype unit to the advanced design was constructed and then tested in a controlled environment chamber at extremes of normal relative humidity.

The general agreement with the design performance was very satisfactory and was within 10% of prediction. Least agreement occurred on the pressure drop and fan power consumption. Heat exchanger correlations do not normally allow for complex entrance and exit conditions. This short counterflow heat exchanger had an unexpectedly high air pressure drop on one circuit, namely the air path with the side entry and side exit.

Overall, the validation confirmed the theoretical design approach.

The presence of the counterflow

heat exchanger did have an unexpected influence on the time taken for the machine to operate at the design conditions. This is due to the added thermal inertia of the heat exchanger which can take several minutes to establish working temperatures. The dehumidifier does not work at its most effective during this warm up time. Narrow differential humidistats with their consequent short on/off intervals are not therefore suitable for this advanced design.

There is good reason to believe that it will be possible to develop a low thermal mass heat exchanger. The other design criteria are resistance to corrosion, compact size, high efficiency and cheapness. However, two aspects of design normally required of a fin and plate heat exchanger are not necessary. This application requires only a small pressure difference between the two air streams, and leakage from one stream to the other is relatively unimportant. Therefore, there are good prospects for a novel heat exchanger fabricated, perhaps, in aluminium foil.

Summary

Mild maritime climates such as Britain's, remain near water vapour saturation conditions for the whole winter. This moisture burden can and does induce problems inside buildings. Moisture removal is therefore necessary at the same time that space heating is needed. Conventional solutions involve a mixture of ventilation and space heating but these are difficult to control and extravagant to run.

The simplest and most effective way of removing water vapour from buildings is by means of a heat pump humidifier. Such units first cool down then reheat the incoming air so that it leaves the unit drier and hotter than when it entered. The heat pump cycle converts the potential energy of the latent heat of the moisture into sensible heat to the air. More energy is supplied to the room than the electrical energy used and the commercially available units have coefficients of performance around 1.2-1.5.

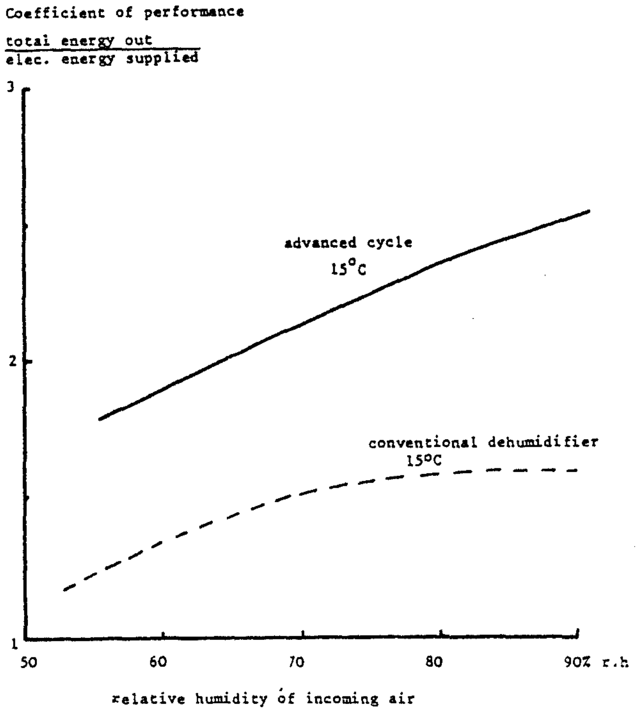

Fig 7
The variation of coefficient of performance with relative humidity

Precise design studies are difficult because the heat exchangers and the compressor are interactive. Changes in any one component affect the other two and involve much computation. Now the low cost and ready availability of digital computers means that complex reiterative design procedures become feasible. Such a design procedure has been successfully applied to dehumidification. In particular, it has revealed the significant improvement in both effectiveness in terms of litres/kWh and moisture extraction rate, which a counterflow air/heat exchanger can create.

A prototype dehumidifier was built to this design and tested in a controlled environment chamber. Test results agreed within 10% of the predictions. Effectiveness in terms of litres of water extracted per unit energy input was more than twice that with conventional equipment. Moisture extraction rate was trebled.

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