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# Adapting a geared domestic refrigerative dehumidifier for low-temperature operation

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ABSTRACT

It has been established that geared domestic refrigerative dehumidifiers behave poorly when operated in low-temperature household environments where frosting of the evaporator occurs. The hot-side temperature drop introduced by the air-side evaporator economiser is a primary factor in the poor performance of the system if the economiser is too efficient. In this paper, methods for pushing the geared dehumidifier frosting limit to lower ambient temperatures are explored numerically and implemented experimentally with a test system. The methods tested here include a modified refrigerant evaporator, control of the economiser's thermal effectiveness and an integrated approach which includes both methods in conjunction with variable air flow. Results presented in this paper demonstrate operation of a geared domestic dehumidifier with improved dehumidification capacity over the conventional system by around 10% at a moist air condition of 15.4 °C, 70% relative humidity, without evaporator frosting.



# Adaptation d'un déshumidificateur frigorifique domestique à engrenages pour le fonctionnement à basse températures

*Mots clés :* déshumidificateur à engrenages ; Givrage ; Conditionnement d'air ; Déshumidification

## 1. Introduction

High indoor humidity is detrimental to occupant health (Cunningham, 2007; Howden-Chapman et al., 1999; Hyndman et al., 1994), it degrades the building fabric (Cunningham, 2007; Hyndman et al., 1994) and contributes to unpleasant odours due to mould (Clausen, 2000). Dampness has been cited as the primary cause of building fabric deterioration (Straube, 2002). Galvin (2010) identifies problems with high humidity in British housing, noting especially the risk of condensation on wall surfaces when the temperature falls over-night.

Studies of the average temperatures in NZ homes have revealed a mismatch between the conditions at which imported dehumidifiers are performance tested and the temperatures at which they are operated. The imported systems are typically tested by the Association of Home Appliance Manufacturers (AHAM) in the range 18.3 °C–32.2 °C

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**Nomenclature**

| | |
|---|---|
| *MER* | Moisture extraction rate [kg $h^{-1}$] |
| *SMER* | Specific moisture extraction rate [kg $kW^{-1}$ $h^{-1}$] |
| $N_{EV}$ | Number of longitudinal evaporator rows [–] |
| $N_{HEC}$ | Number of active hot-side economiser ducts [–] |
| $\dot{m}$ | Mass flow rate [kg $s^{-1}$] |
| $T_{A2}$ | Temperature at the economiser cold side entry [°C] |
| $T_{A3}$ | Temperature at the economiser cold side exit [°C] |
| $T_{db}$ | Dry-bulb temperature [°C] |
| $T_{EV}$ | Saturated evaporating temperature [°C] |
| $T_{EV,\ AIR}$ | Temperature of air off the evaporator [°C] |
| $\Delta T$ | Change in temperature [°C] |
| *Greek* | |
| $\varepsilon_d$ | Dry-side thermal effectiveness [–] |
| $\Phi$ | Relative humidity [–] |
| *Subscripts* | |
| *a* | Air |
| R | Refrigerant |
| DSC | Degree of liquid sub-cooling |
| EC | Economiser |
| EV | Evaporator |
| SSH | Suction super-heat |

(Cunningham and Carrington, 2005). NZ homes on the other hand have a mean evening temperature range of 10–23.8 °C (French et al., 2007) with the average annual room temperature for some being as low as 13.4 °C (Lloyd et al., 2008). This results in dehumidifiers operating outside of their optimum performance envelope. Refrigerative dehumidifiers are known to operate ineffectively at 10 °C (Cunningham and Carrington, 2005), which is far below the lower limit of the AHAM test range.

Improving dehumidification by evaporator gearing, through the use of heat-pipes (Yau and Tucker, 2003) or air-to-air plate heat exchangers (MSP Technology, 2008) in conjunction with the refrigerant evaporator, is well established (ASHRAE, 2008). Evaporator gearing has the potential to reduce the sensible cooling load of the evaporator thus promoting greater latent cooling of humid air at this component (Doderer and Clower, 1981; Dieckmann et al., 2009). Improving domestic scale refrigerative dehumidifiers by gearing was suggested by Blundell (1979). A recent study of directly retrofitting a domestic scale dehumidifier with an economiser (Lowrey et al., 2012) showed that the geared system performance was diminished in that trial, due to evaporator frosting, despite numerical calculations predicting improvements in both the moisture extraction rate (*MER*) and the specific moisture extraction rate (*SMER*). In this paper, we extend on the work of Lowrey et al. and present numerical and experimental results from an investigation of methods that lower the ambient moist air temperature at which the geared dehumidifier may operate without frost forming on the evaporator coil. Two methods are explored. Firstly, the refrigerant evaporator is modified in order to increase the evaporating temperature and lift the evaporator out of the frosting region for a given ambient moist air condition. The other method is controlling the thermal effectiveness of the evaporator economiser. As the thermal effectiveness of the evaporator economiser is increased, the hot-side air temperature drop increases. This leads to cooler air entering the evaporator, and as the thermal effectiveness is further increased, it will start to frost. The evaporator was first modified and tested with the test dehumidifier in the ungeared mode and subsequently tested in the geared mode so direct comparison could be made. Performance data is presented for the ungeared and geared system operating at different ambient relative humidities. This includes a presentation of the geared system dehumidification components including the moisture extraction rates for both the economiser and the evaporator. An integrated method for achieving operation of the geared system at a moist air condition of 15.4 °C and 70% RH is also presented and shows that gearing increases the moisture extraction rate by around 10% relative to the conventional system at this condition.

### 1.1. *The test system and methods*

The test dehumidifier system, shown in Fig. 1, consists of a refrigeration system, extracted from a commercial dehumidifier, coupled with air ducting designed to accommodate either a by-pass (for ungeared operation) or an economiser (for geared operation). Here we limit the system description to the modifications made to the refrigerant evaporator and the evaporator economiser. More details of the test system and its components are given in reference (Lowrey et al., 2012).

#### 1.1.1. *Refrigerant evaporator*

The evaporator was modified to increase the evaporating temperature ($T_{EV}$) in order to operate the geared system at lower ambient moist air conditions without evaporator frosting. The main adjustment to the cooling coil was an increase in the number of evaporator longitudinal rows, $N_{EV}$. The evaporator used in the test dehumidifier system was originally a two row finned tube coil, as shown in Fig. 2A. The refrigerant flow was in-line with the air flow through the fins of the evaporator. The evaporator was modified by adding an identical two row evaporator which was plumbed with the refrigerant flow running counter to the direction of the air flow with two refrigerant circuits in parallel to avoid a large refrigerant-side pressure drop. In this configuration, a needle valve was followed by a 6.35 mm diameter refrigerant line and then split into two capillary tubes 22 cm long, both having an ID of 0.66 mm. One capillary feeds the upper segment of the evaporator, and the other the lower segment, as shown in Fig. 2B.

To balance the two evaporator circuits, the temperatures of the air off the upper and lower segments of the evaporator were checked before a performance test commenced to ensure they were approximately the same. This was to ensure the upper and lower evaporator segments received equal flows of refrigerant. To balance the flow of charge to each evaporator segment, the feeder capillaries were adjusted, by local crushing, until the temperatures of air off the upper and lower segments were in agreement to less than 1 °C.

#### 1.1.2. *Variation in the economiser thermal effectiveness*

The evaporator economiser used in the experimental work was a plate heat exchanger (PHE), previously described in