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A Novel Ventilation Heat Pump System

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SYNOPSIS

The move towards improving building air-tightness to save energy has increased the incidence of poor indoor air quality and associated problems, such as condensation on windows, mould, rot and fungus on window frames. Mechanical ventilation heat recovery systems (MVHR) combined with heat pumps offer a means of significantly improving indoor air quality as well as providing heating and cooling required in buildings.

This paper is concerned with the testing and performance of a novel ventilation heat pump system developed for the domestic market[1,2,3]. The novel system uses revolving heat exchangers which both impel air and transfer heat. Low grade heat recovered from the exhaust air is upgraded by a heat pump and used for heating the fresh supply air. The prototype system has a heating coefficient of performance (COP) of up to 5 and an average system COP of 2.5 over a range of conditions. The system typically provides 2kW of heating for air supplied at 250m^3/hr. The system can also be used for cooling by switching the air flows over the evaporator and condenser. The prototype system requires very little maintenance and is compact and energy efficient.

1. INTRODUCTION

The current concerns over global warming, due to greenhouse gas emissions, have brought about an increased awareness of energy use in the built environment. This has prompted the building of homes which are more energy efficient and consequently more airtight. In the past, homes were draughty with adequate levels of ventilation. This was due to poorly fitting doors and windows, chimneys, and air leakage through gaps in the structure. In recent times, the construction of modern doors, windows, and floors usually provides better seals against the entry of outside air than in the past. Some modern homes no longer have chimneys and often in older homes the chimneys have been blocked-up.

The sealing up of homes, however, has greatly contributed to an increased incidence of poor indoor air quality. Inadequate ventilation can cause problems such as condensation on windows, mould, rot and fungus on window frames, damp patches on walls and dust mites in mattresses and carpets. These problems are detrimental to the fabric of a dwelling and can be damaging to the health of the occupants.

Studies in the USA and elsewhere indicate that approximately 93% of time is spent indoors, 5% of time is spent in transit and only 2% outdoors[4]. The combination of greater concentrations of indoor air pollutants and the amount of time spent indoors, suggests that the exposure to airborne pollutants, with the consequent health risks, is far greater now than in the past. It is therefore necessary to provide acceptable levels of ventilation to remove pollutants and maintain a healthy environment. This should be achieved in a manner that does not compromise energy efficiency.

Since opening a window to improve ventilation defeats the purpose of tightening the building's thermal envelope, an alternative means of providing adequate ventilation is required. Alternatives are passive ventilation through trickle vents on windows or by passive stack ventilation, which relies on stack and wind effects to push air through the dwelling. However, heat is lost with the exhaust air in both these systems and neither can provide a response to periods of high moisture production.

Simple extract fans could be used but, again, heat is lost with the outgoing air and they generally only service individual rooms, which results in poor air distribution. A more efficient method of removing pollutants, and adequately ventilating dwellings, is to use whole house mechanical ventilation (MVHR) systems. A supply fan and duct system provides fresh air to living areas and bedrooms, whilst an extract fan and duct system exhausts stale, moist air from the kitchen and bathrooms. A heat exchanger is used to transfer heat from the exhaust air to the supply air. Space heating bills are reduced by preheating the supply air using recovered heat. The cost of electricity used to run the systems is offset by the space heating savings. Many studies have shown that MVHR systems can significantly improve the indoor air quality of a home.

More advanced MVHR systems incorporate heat pumps to provide the heating and cooling required in buildings. Heat pump MVHR systems can supply warm air at temperatures of up to 50°C. Cool air can be provided by reversing the heat pump cycle. In a well insulated airtight house, such a system can supply up to 80% of the seasonal space heating needs at a coefficient of performance of three[5]. The heat pump's high performance means it consumes much less fuel than conventional heating boilers and so emits only a low quantity of CO_2, the principal contributor to the greenhouse effect. The importance of this is highlighted by the commitment made by the UK Government at the Rio Earth Summit, to return CO_2 emissions to 1990 levels by the year 2000. Although heat pumps are frequently employed for industrial and commercial applications, the domestic market in the UK for these systems has been limited due to their high capital cost and maintenance requirements.

The work covered by this paper is the continuation of previous work by the authors on the development a revolving heat pipe MVHR system[6,7]. A novel ventilation heat pump system has been developed that is compact, has a low capital cost and requires little maintenance. The unit will supply fresh air at up to 250 m^3/hr with effective heating/cooling. This will provide 0.35 air changes per hour for a typical four bedroom detached house. This value complies with the ASHRAE Standard to maintain general indoor air quality.

2. MVHR HEAT PUMP SYSTEM

The MVHR heat pump is based on the integration of revolving wire finned heat pipes with a compressor to facilitate air movement, heat recovery and heat pumping in a single unit. The wire finned pipes are the evaporator and condenser components of the heat pump. Nine pipes revolve within adjacent centrifugal fan casings to both impel air and transfer heat. Heat recovery is effected via a small charge of refrigerant which is vaporized in the evaporator of the heat pipe array then compressed to allow heat rejection to the cool fresh air in the condenser. In operation, the domestic MVHR heat pump system will extract stale air from the kitchen and bathroom, recovering heat from the air in the process. The recovered heat is upgraded by the compressor and is transferred via the array of revolving pipes to the incoming fresh air. The system can be used for summer cooling by switching the air flows over the condenser and evaporator.

The hydrocarbon isobutane (R600a) was used as the refrigerant in the system. Isobutane has very low global warming potential and zero ozone depletion potential. The results of theoretical modeling gave isobutane a high COP with low system pressures. A high COP is good for energy efficiency and low vapour pressures put less stress on the revolving pipe work and seals. The charge of isobutane used (300 grams) is well below the maximum quantity of 1.5kg allowed for flammable refrigerants used in residential heat pump applications[8]. Partitioned PTFE rotary lip seals were developed and used to provide effective sealing of the rotating centre shaft to the stationary pipe work to and from the compressor. Figures 1 and 2 illustrate the operation of the system.

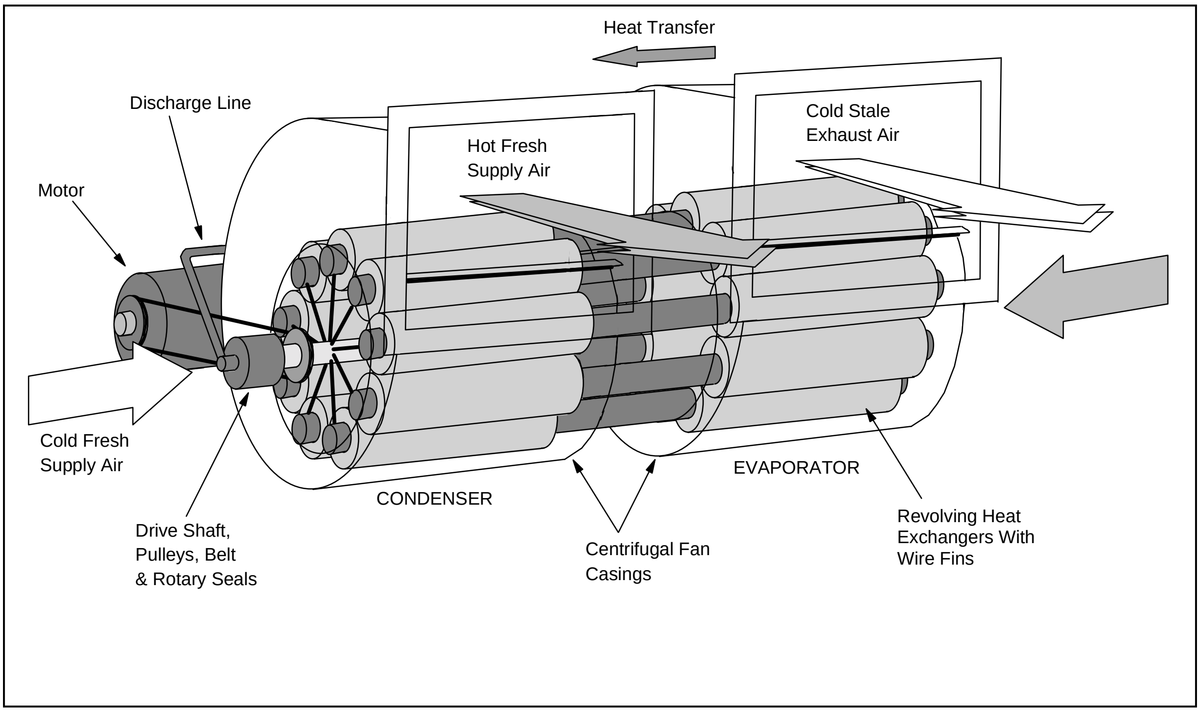

Figure 1. MVHR Heat Pump System

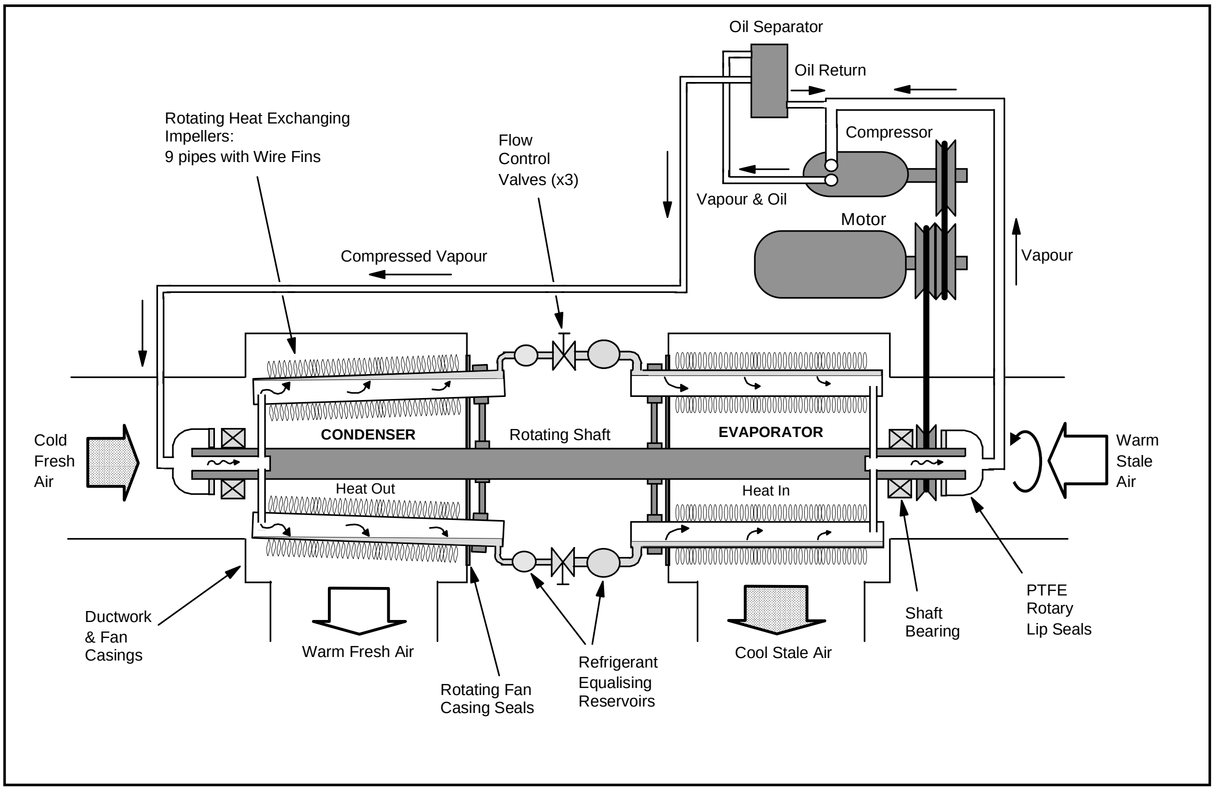

Figure 2: Schematic of MVHR Heat Pump Cycle

3. TESTING OF THE MVHR HEAT PUMP PROTOTYPE

Fan performance tests (type D) were carried out according to clause 18 and 19 of the British Standard[9]. A full set of fan characteristics were found for different speeds of rotation. Figure 3 illustrates the static pressure volume flow rate characteristic for the revolving pipes. The results of testing show that the pipes must revolve at a speed greater than 800rpm in order to generate enough pressure to overcome ductwork losses in a whole house ventilation system.

For different heating/cooling conditions the system was tested varying the following parameters: refrigerant charge, compressor speed, speed of rotation (fan speed), expansion valve settings and airflow. This enabled the best heating/cooling conditions and output for the system to be determined. The system COP, which includes fan power, was found for all combinations of parameters. Figures 4 and 5 illustrate typical heating and cooling characteristics.

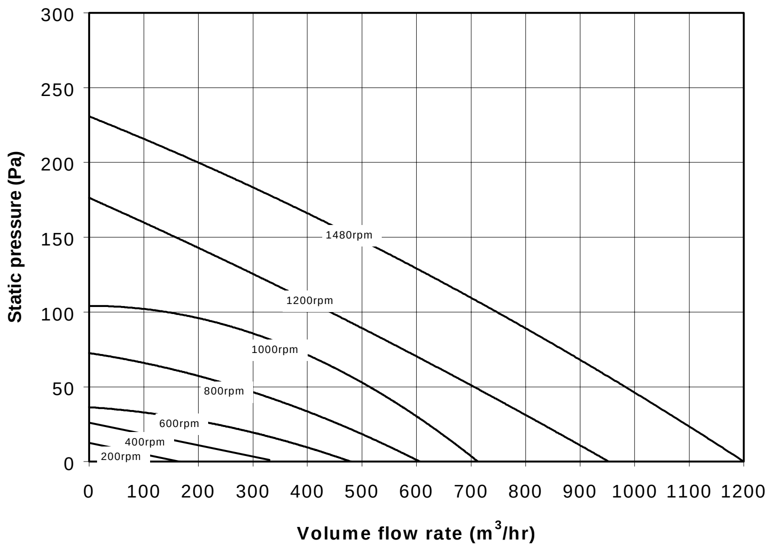

Figure 3. Fan Characteristic for MVHR Heat Pump

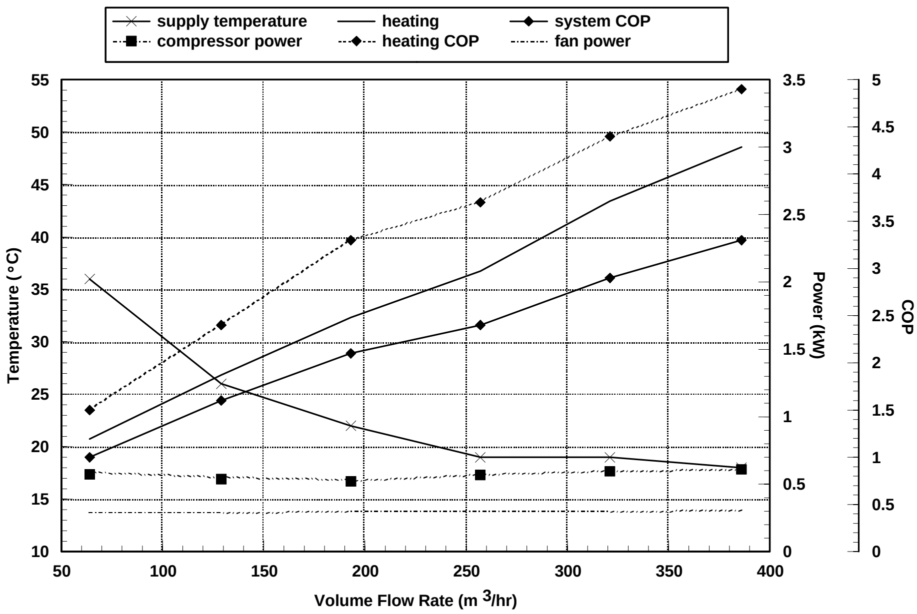

Figure 4. MVHR Heat Pump Heating Characteristic

Supply air inlet temperature = -5°C, Exhaust air inlet temperature = 25°C, Compressor speed = 2175rpm
Fan speed = 800rpm, Valve setting = 0.6, R600a charge = 300grams

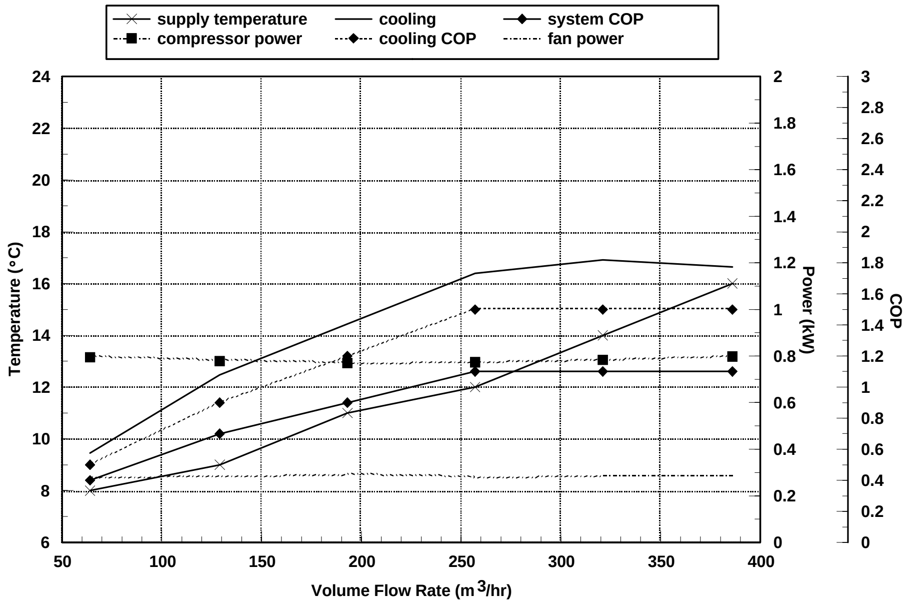

Figure 5. MVHR Heat Pump Cooling Characteristic

Supply air inlet temperature = 25°C, Exhaust air inlet temperature = 20°C, Compressor speed = 2175rpm
Fan speed = 800rpm, Valve setting = 0.6, R600a charge = 300grams

Over a range of air inlet temperatures and air flow rates, when in heating mode, the heating COP ranged between 1.3 and 5 and the system COP ranged between 0.8 and 3.4. When in cooling mode, the cooling COP ranged between 0.5 and 2.6 and the system COP ranged between 0.4 and 1.9. Under typical operating conditions the COPs would be, approximately, at a mid point between these ranges. The fan and compressor power consumption average 300Watts and 600Watts respectively. The system typically provides 2kW of heating or 1.5kW of cooling. When handling air at 260m^3/hr the supply air was heated from 0ºC to 26ºC and the exhaust air was chilled from 20ºC to 6ºC.

4. DISSCUSSION AND CONCLUSIONS

A prototype providing ventilation, heat recovery and heat pumping in one unit has been developed. The system has no requirement for separate fans and heat exchangers eliminating associated fan penalties. The heat transfer characteristics of the revolving pipes were shown to be good due to the relatively high speeds of rotation and the physical characteristics of the wire finning.

The prototype heat pump system provides adequate ventilation with desirable heating and cooling capacities. The system is energy efficient as shown by its good heating and cooling COP's. The high speeds of rotation prevented any frosting and dirt build up on the heat pipes during all periods of testing. In practice this would reduce maintenance and eliminate the need for defrosting the evaporator. The work has shown that an environmentally friendly refrigerant with zero ozone depletion potential and low global warming potential can be used successfully in a novel MVHR heat pump system.

Heat transfer rates could be improved by further optimising the design of the revolving pipes. Fin and pipe geometry could be enhanced to achieve this. At present the fan power is high but could be lowered by reducing the friction present in the fan casing seals and by reducing the overall weight of the rotating pipes and associated components. An efficient motor of a suitable size would also use less power. Future work will incorporate these ideas to achieve lower power consumption.

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