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A NOVEL VENTILATION / HEAT RECOVERY HEAT PUMP

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SYNOPSIS

The trend 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 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 development of a novel ventilation / heat recovery system for the domestic market[1]. The new system has a high theoretical coefficient of performance and uses an "environmentally-friendly" refrigerant. In addition, the heat pump is compact and requires little maintenance. Computer modelling of the system has been carried out using different refrigerants. Several prototype systems have been designed, constructed and tested in the laboratory. These include ventilation heat recovery systems comprised of heat pipes with wire fins.

INTRODUCTION

Over recent years one of the main concerns in housing has been to build homes which are more energy efficient, thereby reducing heating costs, increasing occupant comfort and reducing the amount of pollutants released into the atmosphere by heating systems and power generation processes. This has mainly been achieved by increasing insulation levels, improved window technology, making the building shell more airtight and using efficient heating systems.

The trend 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, damp patches on walls and house mites in mattresses and carpets. Mechanical ventilation/heat recovery systems combined with heat pumps offer a means to significantly improve indoor air quality as well as provide heating and cooling required in buildings.

Recent studies have found that ventilating homes can reduce the number of house dust mites[2]. Dust mites aggravate asthma in over a third of asthmatic patients.

More than two million people in the UK are asthmatic and the numbers are showing a steady increase. In 1989 the National Health Service spent approximately £217 million on drugs for asthma, this is about 8% of the total NHS budget, 670,000 people in the UK could be suffering from asthma because they are allergic to dust mites[3].

In Denmark some studies showed that the health of people with asthma improved considerably when they moved to well ventilated homes which had few dust mites[4].

The heat pumps high performance means it consumes much less fuel than conventional heating boilers and so would emit a much lower quantity of CO_2, the principal contributor to the greenhouse effect. The importance of this was highlighted by the commitment made by the U.K. 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 U.K. for these systems has not been large and widespread use of heat pumps in domestic buildings has been limited due to their high capital cost and maintenance requirements.

A novel ventilation / heat recovery system has been developed that is compact, has a low capital cost and requires little maintenance. The unit will supply fresh air at 200 m^3/hr with effective heat transfer. 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.

DESCRIPTION OF THE SYSTEM

The ventilation/heat recovery heat pump is based on the integration of a rotary heat pipe/metal fibre impeller with a compressor and/or ejector unit, which allows air movement, heat recovery and heat pumping to be carried out in a single unit. The unit consists of a rotating heat pipe array which has metal fibre extended surfaces and incorporates a compressor or/and an ejector. The metal fibres act as impellers and efficient heat exchangers by presenting a large surface area to the air they move. The heat pipe array is contained within conventional centrifugal fan casings, arranged to allow warm extract air to pass over the evaporator section of the heat pump and cool fresh air to pass over the condenser section. 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 ventilation/heat recovery 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/or ejector and is transferred via the heat pipe array to the incoming fresh air.

HEAT PUMP PERFORMANCE

The basic measure of performance of a heat pump is its coefficient of performance (COP), which is defined as the ratio of useful heating effect to the rate of energy input to the system. A BASIC language computer program has been written to model the steady state coefficient of performance of the ventilation/heat recovery heat pump. Equations of state were used to predict the thermodynamic condition of various refrigerants around the vapour compression cycle. The refrigerants investigated were water, methanol, pentane, R32, R407a, CARE 10, CARE 30, CARE 40 and CARE 50.

As this system is intended for domestic applications, the temperature of the extract air stream from which heat is recovered is taken as constant at 20°C. With the heat source temperature fixed, the evaporator temperature is determined by allowing a terminal temperature difference of 10°C between the refrigerant and the extract air, fixing the evaporator temperature at 10°C. The condenser temperature is determined by selecting a typical warm air supply temperature of 20°C and again allowing a refrigerant to air temperature difference of 10°C, fixing the condenser temperature at 30°C. Having determined the evaporator and condenser temperatures the COP of the ventilation/heat recovery system can be calculated and the results are presented in Table 1.

Refrigerant	Evaporator pressure (bar abs.)	Condenser pressure (bar abs.)	Compressor power (W)	Suction volume (m^3/hr)	C.O.P.
Water	0.012	0.042	64.7	149.7	15.44
Methanol	0.074	0.218	119.6	29.6	8.37
Pentane	0.50	1.14	78.6	6.63	12.69
R32	11.06	19.28	81.0	0.42	12.35
R407a	7.51	13.48	77.7	0.61	12.87
CARE 10	2.21	4.04	82.2	1.92	12.17
CARE 30	3.8	6.70	68.5	1.17	14.61
CARE 40	6.36	10.85	81.3	0.80	12.29
CARE 50	7.29	12.00	80.7	0.71	12.40

Table 1. Coefficients of performance for various refrigerants in the Ventilation / heat recovery heat pump.

As Table 1 shows, water is the refrigerant with the highest COP but it also has the highest compressor suction volume, meaning a compressor with a large physical size is required. As a compact and low cost system is desirable water is therefore considered to be unsuitable for use in this system. Methanol is also rejected due to its relatively low COP and high suction volume. The remaining refrigerants all merit further consideration: pentane for its high COP and operating pressures close to atmospheric, the remainder for their high COPs and low suction volumes.

ROTATING HEAT PIPES WITH METAL FIBRE EXTENDED SURFACES

The extended surfaces of the rotating heat exchangers must provide an efficient means of transferring heat from the extract air and to the supply air. A theoretical fin efficiency analysis of various extended surface profiles has been carried out for the above operating temperatures and optimum fin heights and profiles were obtained. Testing has been carried out on a rotating heat pipe array without a compressor to determine its effectiveness as a heat exchanger.

The Rotating Heat Pipe Heat Recovery System was tested to measure the efficiency of the heat pipe array as a fan and as a heat exchanger. Figure 1 illustrates the experimental set-up of the test rig.

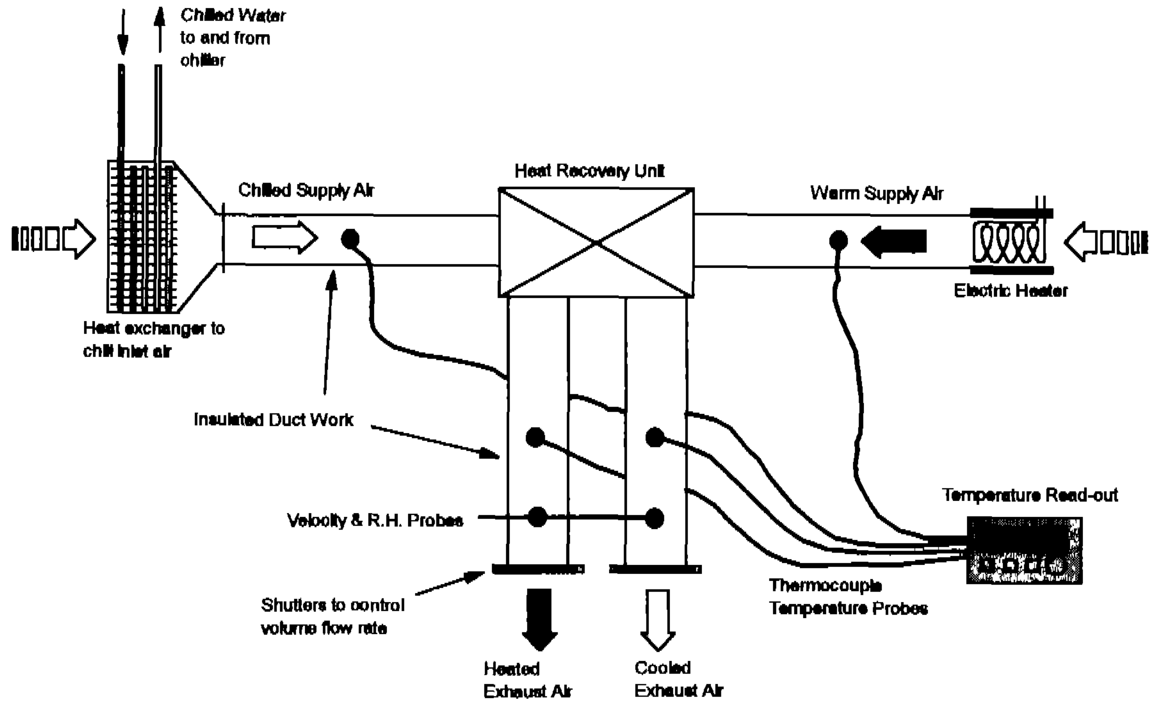
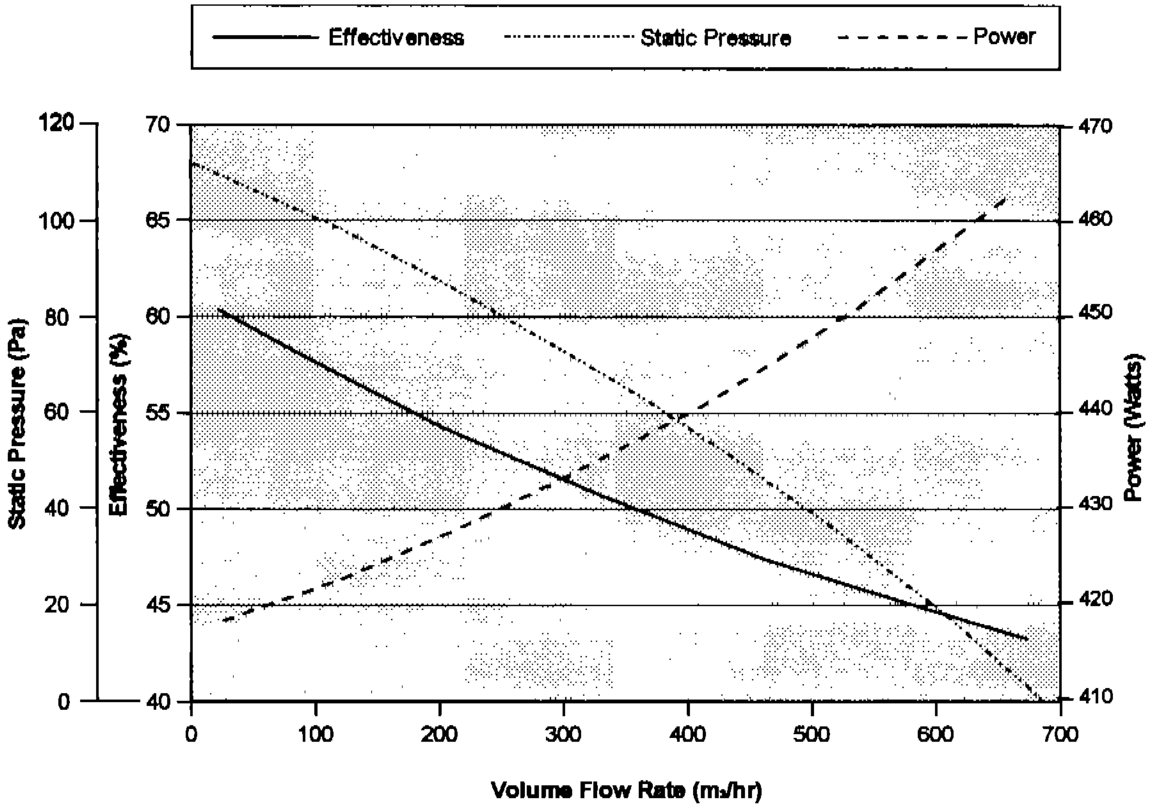


Figure 1: Experimental Set-up of Test Rig

The test rig was tested for a range of operating temperatures, rotational speeds, refrigerant volume fills, heat pipe numbers and geometry, fin heights and profiles. The range of results obtained were used to design the optimum heat pipe heat exchanger configuration.

Figure 2 shows a typical set of results for the Rotating Heat Pipe Heat Exchanger. The results shown are for a heat pipe array rotated at 900 rpm. Each copper tube was evacuated and contained a refrigerant fill of water. Screen mesh wicks were used to aid refrigerant return from the condensers to the evaporators. The evaporator and condenser sections of the pipes were covered with dense copper wire loop fins.



Speed of Rotation - 900 rpm,
Exhaust Air Inlet Temperature = 20°C, Supply Air Inlet Temperature = 0°C

Figure 2: Characteristic Curves for Heat Pipe Heat Recovery System

DISSCUSSION AND CONCLUSIONS

The rotating pipes with wire fins have been shown to provide adequate rates of ventilation. At 1480 rpm the rotating heat pipe impeller can supply air at 1200m^3/hr. The static pressure produced by the impeller is more than adequate to overcome any duct losses in a whole house ventilation system.

Use of heat pipes alone without a compressor provides good levels of heat recovery. The Rotating Heat Pipe Heat Recovery System has 55% effective heat recovery at 170m^3/hr. This compares with 65% effective heat recovery for commercial static plate heat exchangers handling the same air volumes.
Heat transfer rates could be improved by further optimising the design of the rotating heat pipes. Fin and pipe geometry could be enhanced to achieve this.

The levels of power consumption could be dramatically lowered by reducing the friction present in the fan casing seals and by reducing the overall weight of the rotating pipes and clamps.

Currently tests are being carried out on the heat pump system. Results to date compare well with the theoretical values illustrated and will be presented in a future paper.

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