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Research Paper

Thermal performance of a multi-loop pump-driven heat pipe as an energy recovery ventilator for buildings

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HIGHLIGHTS

- The multi-loop pump-driven loop heat pipe was first used for building energy recovery.
- The performance of both single-loop and triple-loop system were tested and compared.
- The uniformity of heat exchanging temperature difference was analyzed.
- The improvements of triple-loop system were obvious in winter condition.
- In summer condition the performance of triple-loop system was not enhanced.

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ABSTRACT

Building energy consumption could benefit from air-to-air energy recovery ventilators. A triple-loop pump-driven heat pipe system was developed for energy recovery from exhaust air in buildings. The thermal performances of the single-loop and triple-loop systems were studied and compared experimentally under winter and summer conditions. The improvement of loop number and the uniformity of temperature difference distribution was discussed. Results indicated that heat transfer capacity and coefficient of performance increased with indoor and outdoor temperature difference, and the variation of temperature effectiveness depended on working conditions. The energy recovery performance of the triple-loop system was better than the single-loop system. The heat transfer capacity, temperature effectiveness, and coefficient of performance of the triple-loop system increased by 3.0%, 0.6%, and 56.7% in summer conditions with an indoor and outdoor temperature difference of 7.5 °C, and by 22.4%, 22.6%, and 53.5% in winter conditions with an indoor and outdoor temperature difference of 31.9 °C. The uniformity of temperature difference distribution could be improved clearly with increasing loop number in winter conditions but not obviously in summer conditions. The variation coefficient of temperature difference decreased from 17.2% to 10.2% in winter conditions, and from 4.5% to 3.9% in summer conditions.

1. Introduction

The total building energy consumption of China takes 16.2% of the world building energy consumption [1], which is 19.12% of the national energy consumption in China [2]. Large quantity of fresh air must be brought into buildings to meet the requirement of indoor air quality (IAQ), which results in high energy consumption for heating and cooling fresh air. The energy consumption of heating, ventilating, and air conditioning (HVAC) systems occupies over half of the total building energy consumption. The application of an energy recovery ventilator (ERV) for preheating/precooling fresh air is an effective solution to reduce the energy consumption of buildings using exhaust and fresh air systems for 24 h/day [3,4]. The ERV can reduce building energy consumption by transferring 40% to 80% of sensible and latent heat between exhaust air and fresh air streams [5,6], especially for occasions with polluted air, high IAQ requirement, or full fresh air HVAC system [7].

ERVs are studied on energy recovery effectiveness for IAQ [8,9] and are widely used in residential [10,11] and commercial buildings in many countries [12,13]. The public building code in China issued in 2005 states that an ERV should be installed in HVAC systems when it is rational for technical economic comparison [14]. For energy recovery evaluation, the coefficient of performance (COP) should be more than five besides energy recovery effectiveness [15]. Liu et al. [16] studied the performance of an ERV in different climatic zones in China with weighted coefficient equations. Liu and Niu [17] proposed an analysis

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Nomenclature

COP	coefficient of performance
d_o	outer tube diameter, mm
d_i	inner tube diameter, mm
h_{11}	inlet air enthalpy of exhaust air heat exchanger, kJ/kg
h_{12}	outlet air enthalpy of exhaust air heat exchanger, kJ/kg
l	tube length, mm
m_1	air-side mass flow rate of exhaust air heat exchanger, kg/s
n_x	number of tube rows for facing air
n_y	number of pipe rows for air
Q	heat transfer rate, kW
s_f	fin spacing, mm
s_x	tube spacing for facing air, mm
s_y	tube spacing for air, mm
T_{11}	inlet air temperature of exhaust air heat exchanger, °C
T_{12}	outlet air temperature of exhaust air heat exchanger, °C
T_{21}	inlet air temperature of fresh air heat exchanger, °C
W_1	fan power of exhaust air heat exchanger, kW
W_2	fan power of fresh air heat exchanger, kW
W_3	pump power, kW
ΔT	temperature difference between indoor air and outdoor air, °C
δ_f	fin thickness, mm
δ_t	tube thickness, mm
η	temperature effectiveness,%

Subscripts

1	exhaust air heat exchanger
11	inlet of exhaust air heat exchanger
12	outlet of exhaust air heat exchanger
2	fresh air heat exchanger
21	inlet of fresh air heat exchanger
3	pump
f	fin
i	inner
o	outer
t	tube
x	facing air direction
y	air direction

method from practical application, which was to minimize material cost at a specified fan energy use or to minimize the fan energy use at a given material cost at any given mass flow rate, temperature difference, and desired energy recovery effectiveness. Simonetti et al. [18] studied a new low pressure flat plate heat exchanger for passive ventilation of buildings in order to minimize the need for fans. Six different ERVs have been analyzed and compared in the United Kingdom, and heat pipes and rotary thermal wheels have been suggested as the most potential technologies due to their high thermal efficiency and low pressure loss [19,20]. However, fresh air cannot be isolated from exhaust air in the rotary thermal wheels; thus, fresh air may be contaminated by exhaust air, although its energy recovery effectiveness is high. When fresh air duct and exhaust air duct are apart or several fresh/exhaust air ducts exist, split heat pipe is available as an ERV [21,22] but not conventional heat pipe, thermosyphon [23], or micro heat pipe array [24]. Split heat pipe must start up under some suitable temperature difference, which requires a further study [21]. Such a heat pipe only works while the condenser is installed higher than the evaporator. Weak driving force (capillary or gravity) is another disadvantage of split heat pipe, especially for multi-condenser/evaporator system. For spay drying equipment and heat transfer enhancement, Chen et al. [25,26] developed a heat circuit propelled by a pump or fan based on the split heat pipe. However, for energy recovery in buildings, the working temperature range, pump type, and working fluid are totally different compared with desiccation. The investigations on pump-driven loop heat pipe (PLHP) as an ERV in buildings have been hardly indexed in publications.

For solve the problems from the split heat pipe as EVRs, we designed and proposed a PLHP with strong driving force as a new ERV [27], which eliminated the installation and height difference requirements and could be used widely. The single-loop PLHP as an ERV was developed by our group, and the influences of working fluid, mass flow rate, heat exchanging area and facing air velocity were studied experimentally [28,29]. However, we found that the maximum temperature effectiveness limit existed for the single-loop PLHP when the heat-exchanging area or pipe row number increased [30]. How to exceed the temperature effectiveness limit of the single-loop PLHP when both the heat exchanging area and pipe row number are constant? Whether the loop number change is helpful to improve the performance of PLHP or not? How much the improvement of loop number change? These are the problems that need to be solved for PLHP EVRs.

For exceeding the temperature effectiveness limit of the single-loop PLHP, a triple-loop PLHP as an ERV was developed and studied experimentally by changing flow path layout in this paper. The thermal performance of the triple-loop PLHP EVR was tested in a standard psychrometric laboratory. The thermal characteristics of the single-loop and triple-loop systems were compared when the heat exchanging area and pipe row number were the same. The improvement of loop number

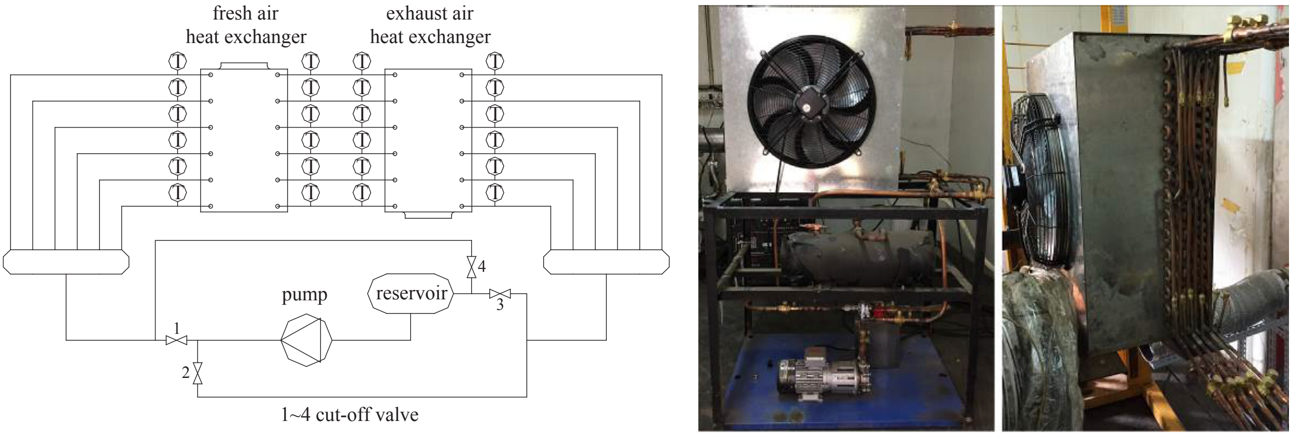

Fig. 1. Schematic of a single-loop PLHP as an ERV.