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Performance evaluation and experimental study on heat recovery device

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Abstract
Heat recovery device are popular utilized in the air-conditioning systems to recovery the energy from indoor exhaust air. Heat recovery efficiencies, including enthalpy recovery efficiency, sensible heat or latent heat recovery efficiency, are adopted as index to evaluate the device's performance. However, more transportation energy will be consumed with the heat recovery device, such as fan consumption due to more pressure drop through the heat recovery device. The recovered energy of the device is cooling or heating capacity (Q), and the consumed transportation energy is electricity (W). A heat recovery COP is then defined as Q/W, which has similar definition as that of chiller. The amount of recovered energy Q will have to be removed by conventional air-conditioning system without heat recovery device. Therefore, the reference COP is calculated by Q divided by the energy consumption of the air-conditioning system. Experimental study on the enthalpy recovery wheel is carried out, with silica gel as the solid desiccant. Heat recovery efficiencies as well as energy consumption of the fans are experimentally obtained. The building in Nagoya and Beijing are investigated, the annual heat recovery COPs and the reference COP are compared. The larger difference between indoor and outdoor parameters, the heat recovery device has more superiority. The performance of heat recovery device is better in Nagoya even with the same heat recovery device.

Keywords – heat recovery device; recovery COP; recovery efficiency

1. Introduction

Air-conditioning energy consumption accounts for 20%-40% of primary energy consumption in developing countries and for around 40% in developed countries [1]. Heat recovery devices provide relevant energy saving in air-conditioning field, reducing heating and cooling load [2]. They work between outdoor air and indoor exhaust air sufficiently recovering cooling or heat from exhaust air depending on the room's environmental conditions. Heat recovery devices can be classified into two types: sensible heat recovery devices and enthalpy recovery devices.

Sensible heat recovery devices include plate heat exchangers, heat pipe exchangers, sensible heat recovery wheels, etc. sensible heat recovery devices can only recover sensible heat from the exhaust air. Enthalpy recovery devices have higher efficiency than sensible only recovery devices which are capable of recovering sensible and latent heat from the indoor exhaust air [3,4]. Enthalpy recovery devices include plate enthalpy heat exchangers, devices using rotary wheels and liquid desiccants.

When energy analysis of buildings and HVAC systems is carried out, heat recovery devices performance should be properly evaluated. To evaluate the performance, a key parameter is the recovery efficiency since it directly reflects the effectiveness of the heat and mass transfer process. The conventional recovery efficiency is widely used in most of the current researches in analysis and comparisons of heat recovery devices [5-8]. However, the parameter only focuses on the recovery degree of perfection without considering energy consumption during the process [9,10]. While heat recovery devices save in cooling or heating capacity, more fan energy is consumed. Therefore, a more intuitive parameter is introduced to determine if the energy saved from the heat recovery devices greater than the energy consumed by the fans.

2. Recovery COP evaluation

The heat recovery COP of devices can be defined by Eq. (1), where Q_r represents the energy recovered and W_{fan} represents the fan power. Thus, the overall heat recovery COP considers heat recovery and the fan's power.

$$COP_{rec} = \frac{Q_r}{W_{fan}} \tag{1}$$

For a conventional air-conditioning system without a heat recovery device, the consumption power is composed of the compressor power, the pump's power, the cooling tower power, and the fan's power. After adding a heat recovery device, the recovery device assumes part of cooling demand (Q_r). Additionally, the cooling quality of chillers will decrease from Q_e to (Q_e- Q_r), where Q_e represents the cooling quality of chillers without a heat recovery device. Therefore, the compressor power will decrease and the fan power will increase due to a high-pressure loss across the heat recovery device. Only when total power consumption decreases will the heat recovery device save energy. The reference COP is calculated by Eq. (2).

$$COP_{reference} = COP_{source} = \frac{Q_e}{W_{source}} = \frac{Q_e}{W_{compressor} + W_{pump} + W_{tower}} \tag{2}$$

Increase in fan power can be derived by the heat recovery COP and the heat recovery capacity. To determine if heat recovery devices can save energy, the reference COP is used to compare with the heat recovery COP as defined by Eq.(2). If the heat recovery COP is higher than the reference COP, then the increase in required fan power is less than the decrease in required compressor and pomp power. Therefore, heat recovery devices can reduce total energy consumption of an HVAC system. Alternately, when the fan consumes more energy than the compressor and pumps can save, heat recovery devices are not needed.

The heat recovery COP may be influenced by device characteristics and operating conditions. Device characteristics include the heat exchanger area, the heat transfer coefficient and pressure loss across the system. Operating conditions include indoor and outdoor air conditions and the volume of the two airflows that represents the heat transfer potential. For a given heat recovery device, the device characteristics have already been determined. Therefore, changes to the heat recovery COP will occur when changes to the air parameters take place. Heat recovery devices are less efficient methods than chillers when the heat recovery COP is lower than the reference COP. In this situation, heat recovery devices should be bypassed thereby preventing excess consumption of fan power.

3. Experimental data

3.1 Experimental results of enthalpy recovery wheel

An enthalpy recovery wheel consists of a cylindrical rotating device made of rolled-up corrugated sheets of metallic material to get a quantities of parallel channels with a typical sinusoidal or triangular cross sectional geometry. The substrate is coated with a sorption material to adsorb water vapor. The outdoor fresh air steam and the exhaust air steam from the building pass through the cross section of the wheel.

An enthalpy recovery wheel from a manufacturer was experimentally evaluated as shown in Fig. 1. The technical specifications and operating parameters are listed in Table 1. As indicated in Fig. 1, Room 1 and Room 2 of the enthalpy difference laboratory were set at different temperatures and humidity ratios. Room 1 was designed as an indoor space, while Room 2 was designed as an outdoor space. The rotary wheel was controlled with a frequency converter allowing the rotation speed to be varied from 252 r/h to 1260 r/h as the frequency was increased from 10 Hz to 50 Hz. The temperature was measured with thermocouples with an error rate of ±0.1 ℃, and the relative humidity was measured using a temperature and humidity recorder (WSZY-1A) with a ±2% RH error rate. A series of experiments were conducted at different rotation speeds, air inlet parameters, and air volumes.

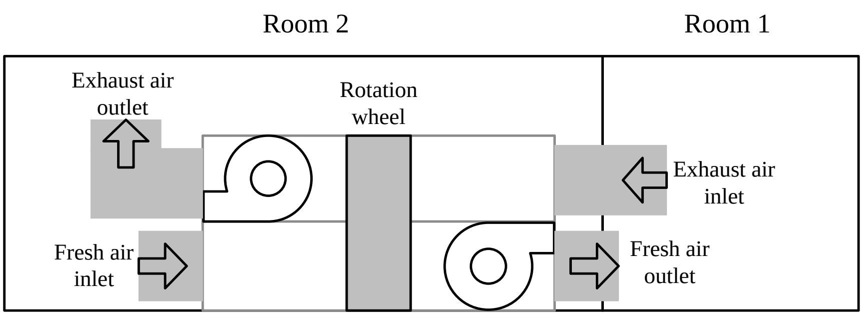


Fig. 1 Enthalpy recovery wheel experimental setup

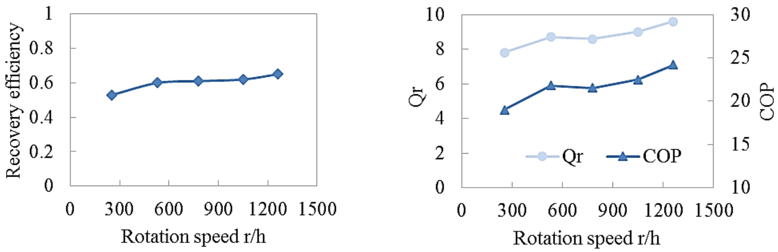
Table 1 Enthalpy wheel information and operating parameters

Device information		Operating parameters	
	Radius: 210mm		24 ℃~28 ℃, 8.4g/kg~13.5g/kg
Wheel	Thickness: 200mm	Indoor air condition	600 m³/h~1260 m³/h
	Rated power: 0.2kW		27.5 ℃~37 ℃, 12.3g/kg~26.7g/kg
Fans	Rated air volume: 1400m³/h	Outdoor air condition	900 m³/h~1940 m³/h
Wheel	Frequency: 50Hz		
Motor	Power: 0.09kW	ratio (Q_{out}/Q_{in})	1~1.5
		Rotation speed	252 r/h~1260 r/h
		frequency converter	10 Hz~50 Hz

Fig. 2 shows experimental results at different operating conditions. Air volume was adjusted by air valve and the fan's power was considered the same as the rated value. For the given technical specifications and operating parameters, the recovery efficiency varied within a range of 40%~70%, the recovery heat varied within a range of 6~14 kW, and the heat recovery COP varied from 15~30. For a dehumidification desiccant wheel, the recovery COP is defined as Eq. (3). The wheel motor power was less than 15% of fan power.

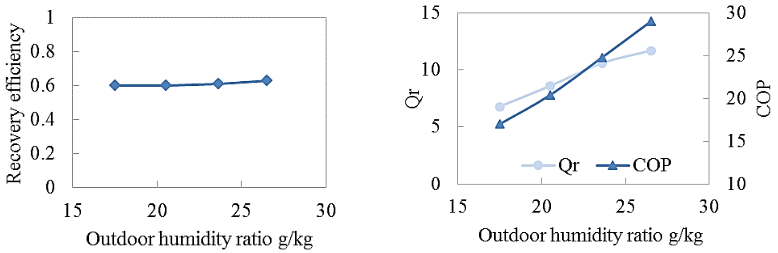
$$COP_{rec} = \frac{Q_r}{W_{fan} + W_{motor}} \tag{3}$$

As shown in Fig. 2(a), the recovery efficiency is relatively unchanged at high rotation speeds, so the recovery heat and COP stay constant. The outdoor humidity ratio and temperature have no impact on recovery efficiency, however, they have a significant impact on the recovery heat and COP. With the rotation speed increasing, the recovery heat and COP have obvious growth. This is due to the changing temperature and humidity differences between two airflows as shown in Fig. 2(b), the lager the differences, the higher the recovery heat and COP. It comes out that efficiency and COP decrease with exhaust air decreasing.



Q_{out}=900 m^3/h T_{out}=35 ℃ d_{out}=26 g/kg Q_{in}=770 m^3/h T_{in}=25.5 ℃ d_{in}=11 g/kg

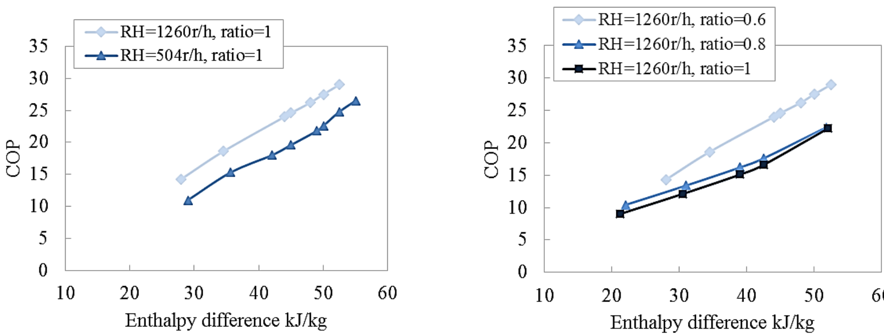
(a) Results at varied rotation speed



Q_{out}=1000 m^3/h T_{out}=35 ℃ Q_{in}=1100 m^3/h T_{in}=25 ℃ d_{in}=9 g/kg R_s=1260 r/h

(b) Results at varied outdoor humidity ratio

Fig. 2 Experimental results (enthalpy recovery efficiency,COP, recovery heat) of enthalpy wheel



(a) Results at varied rotation speed

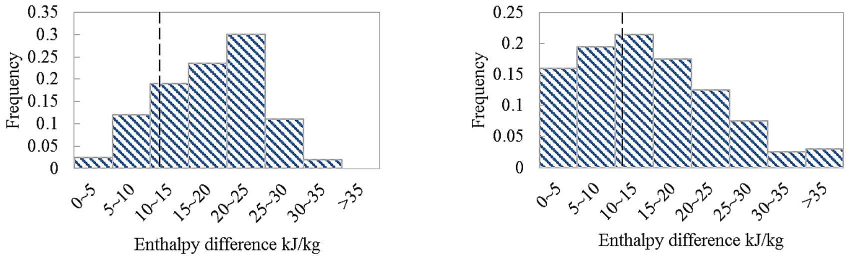
(b) Results at varied air volume ratio defined by the ratio of indoor air volume to outdoor air volume

Fig. 3 Experimental results of enthalpy wheel at different inlet enthalpy differents

Fig. 3 indicates that the inlet parameters such as the enthalpy difference have a significant impact on heat recovery COP. Furthermore, the rotation of the enthalpy wheel and air volume ratio also impact the COP. Hence, the ambient climate of a city is a key influence on the COP. When the outdoor air conditions are similar to indoor air conditions, the enthalpy wheel cannot support high efficient heat recovery. On the contrary, the heat recovery device has more superiority when there are larger differences between indoor and outdoor parameters.

3.2 Case study for enthalpy recovery wheel in different cities

Fig. 4(a) shows the enthalpy difference frequency between indoor air and outdoor air in the cooling season assumes the reference COP is 4.0, the rotation speed and air volume ratio are 1260r/h and 1 respectively. Using the data shown in Fig. 3(a), the COP correlation formula is determined as COP_{rec}=0.6067Δh-2.2677 and Δh is inlet enthalpy difference between indoor and outdoor air. By comparing the heat recovery COP and the reference COP, a reference line can be obtained as shown in Fig. 4. The reference line indicates that during the cooling season, the heat recovery desiccant wheel can be installed in 80% of the time in Nagoya. For the other 20% of the time, installation of a desiccant wheel will not reduce energy consumption of an HVAC system, and in this situation, the heat recovery device should be bypassed in order to avoid excessive energy consumption of the recovery device. Similarly, the heat recovery desiccant wheel is supposed to install in 60% of the time and bypass in the other 40% of the time in Beijing.



(a) Nagoya (b) Beijing

Fig. 4 Enthalpy difference frequency figures in different cities

4. Conclusion

This paper focuses on the evaluation of the heat recovery device's performance. Heat recovery devices can reduce energy consumption when running at proper parameters. The recovery efficiency can indicate device performance, however, the recovery COP provides a straightforward method for evaluating if a heat recovery device will save energy. This evaluation is based on a comparison of the reference COP that is determined from chillers and pumps with the recovery COP.

For all types of heat recovery devices, the heat recovery COP is influenced by outdoor and indoor air parameters and air volumes. While outdoor air conditions are similar to indoor air conditions, the heat recovery COP may be lower than the reference COP. Under this circumstance, the heat recovery device recovers cooling or heat by consuming more energy than cooling or heat sources indicating the heat recovery devices should be bypassed. Additionally, during the transition season, outdoor air can handle indoor cooling load and the heat recovery device must be bypassed to reduce resistance pressure drop.

5. Acknowledgment

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