Sustainable Energy Technologies and Assessments 18 (2016) 127–133

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

journal homepage: www.elsevier.com/locate/seta

Original article

Thermal performance prediction and analysis on the economized vapor injection air-source heat pump in cold climate region of China

Dong Zhang [a,b,c], Jinping Li [a,b,c,*], Junhu Nan [a,b,c], Linjun Wang [a,c]

[a] Western China Energy and Environment Research Center, Lanzhou University of Technology, 730050 Lanzhou, China
[b] School of Energy and Power Engineering, Lanzhou University of Technology, 730050 Lanzhou, China
[c] Key Laboratory of Complementary Energy System of Biomass and Solar Energy, Gansu Province, 730050 Lanzhou, China

ARTICLE INFO

Article history:
Received 20 May 2016
Revised 9 October 2016
Accepted 25 October 2016

Keywords:
Air source heat pump
COP
Economized vapor injection
Thermal performance prediction
Cold climate

ABSTRACT

The air-source heat pump with an economized vapor injection technique has the distinct advantages of performance and stability for space heating and hot water supply in cold area. However, it is unreasonable to evaluate and predict the thermal performance by the nominal working conditions in different areas and environmental conditions. The experimental set up of economized vapor injection air-source heat pump (EVI-ASHP) system was established in cold region of China. The experimental results showed that the air-source heat pump with the EVI technique could improve thermal performance 4–6% than that without EVI. The relationship of COP and condenser inlet and ambient temperature difference was linearly dependent in the same environmental relative humidity. In order to obtain the empirical equations of COP, the linear and negative exponential corrections of the temperature difference of ambient dry-bulb and wet bulb were used when the electromagnetic valve is on or off, respectively. The monthly and hourly thermal performance of four cities in cold and severe cold region in China was compared and analyzed in the climatic condition of the typical meteorological year.

1. Introduction

The space heating and hot water consumption are the very important parts of total building energy consumption in North of China. Air source heat pump (ASHP) which is recognized as an energy saving technology has been widely used for space heating and hot water supply in central and southern China in winter, where the ambient temperature is comparatively more higher than North of China [1]. However, the conventional devices with a single-stage compression cycle cannot operate efficiently and steadily for a long period in cold region because of the lower ambient temperature and frost formation [2,3]. Many studies have been conducted to solve these problems [4–8]. And economized vapor injection (EVI) technic was recognized as an effective method to improve system performance [9].

Currently, a large number of researches have been available on the economized vapor injection air-source heat pump (EVI-ASHP) [6,7,10–16]. Huang et al. investigated the detailed performance for EVI ASHP in a field trial with repeatable ambient conditions cases in UK. By operating a 30 min defrost interval and with increased airflow around the evaporator the EVI ASHP could satisfy the requirements for daily heating demand under freezing conditions in the similar maritime island climates [6]. Wang et al. built an 11 kW two-stage heat pump system with vapor-injected scroll compressor using R410A as a refrigerant. As compared to the conventional system, the new system had about 30% heating capacity improvement with 20% COP gain at the ambient temperature of −17.8 °C [7]. Ma et al. presented the design method of an EVI heat pump system with ejector. The measured results demonstrated that the heating EER (energy efficiency ratio) of the heat pump system with ejector could reach about 4% higher than that of the system without ejector when the heating capacity remained nearly constant [10]. Kim et al. measured the cooling and heating performances of R410A and R32 multi-heat pumps with a sub-cooler vapor injection, and compared with variations in the outdoor temperature, compressor speed, and injection ratio [12]. Yu et al. proposed a novel ejector enhanced vapor injection cycle (EVIC) for air-source heat pumps. The system with R22, R290 and R32 have 2.6–3.1%, 3.2–3.7% and 2.9–3.1% improvement in COP compared with those of the basic vapor injection cycle [15]. The literature review about the economized vapor injection air-source heat pump is shown in Table 1. All the above studies somewhat draw the same conclusion that vapor injection technique could

* Corresponding author at: Western China Energy and Environment Research Center, Lanzhou University of Technology, 730050 Lanzhou, China.
E-mail addresses: zhangdong@lut.cn (D. Zhang), lijinping77@163.com (J. Li).

http://dx.doi.org/10.1016/j.seta.2016.10.008
2213-1388/

Nomenclature

a_1–a_{10}	fitting coefficients
ASHP	air-source heat pump
$c_{p,w}$	specific heat of water (J/(kg · K))
COP	coefficient of performance of heat pump
d	humidity ratio (kg vapor/kg air)
d_s	saturated humidity ratio (kg vapor/kg air)
EER	energy efficiency ratio
EVI	economized vapor injection
EVIC	enhanced vapor injection cycle
p_s	water vapor pressure in the saturated moist air (Pa)
p_v	water vapor pressure in moist air (Pa)
PM	post meridiem
Q_c	the heat gain at the double-pipe heat interchanger (W)
q_w	volume flow rate (m^3/s)
RTD	resistance temperature detector
t_a	environmental dry-bulb temperature (°C)
t_i	inlet temperature of water in double-pipe heat exchanger (°C)
t_o	outlet temperature of water in double-pipe heat exchanger (°C)
t_w	environmental wet-bulb temperature (°C)
TMY	typical meteorological year
TXV	thermostatic expansion valve
W_{com}	electric power input to the heat pump except the water pumps (W)
γ	latent heat of vaporization (kJ/kg)
ρ_w	density of water (kg/m^3)
φ	environmental humidity (%)

Table 1
The experimental systems of EVI-ASHP in recent years.

No.	Year	Author	Heating/cooling capacity	Rating power	Refrigerant	Stage	Country
1	2007	Huang M.J. [6]	11 kW	–	407C	Single	UK
2	2008	Yunho Hwang [7]	11 kW	–	R410A	Two	USA
3	2011	Ma Guoyuan [10]	–	4.55 kW	R22	Single	China
4	2012	Cabello R [11]	–	–	CO_2	Single	Spain
5	2014	Kim Yongchan [13]	6.5 kW	–	CO_2	Single	Korea
6	2014	Navarro-Peris E [14]	–	–	R407C, R290, R22, R32	Two	Spain
7	2015	Yu Jianlin [15]	–	–	R22, R290, R32	Single	China
8	2016	Kim Yongchan [12]	28 kW	–	R410A, 32	Single	Korea
9	2016	Yan Gang [16]	–	–	R410A	Single	China

improve COP of the system in lower ambient temperature. But the studies about the thermal performance evaluation and prediction are not enough. It's strangling the industrialization application of heat pump in space heating, hot water supply and agricultural products drying areas.

Nowadays, in China, the COP of air-source heat pump including economized vapor injection type is evaluated by the nominal working conditions (dry-bulb and wet-bulb temperature are 7 °C and 6 °C, respectively). It is difficult to accurately reflect and evaluate the actual thermal performance in different areas, where the environmental temperature and humidity may change greatly. In the present work, in order to analyze the performance of EVI-ASHP in different regions and provide a theoretic guide for industrialization promotion, thermal performance of an experimental set-up of EVI-ASHP for radiant floor heating is investigated. The fitting equations of COP with and without EVI technique are obtained and verified. Four different cities in North of China are chosen to analyze the monthly and hourly thermal performance of the system.

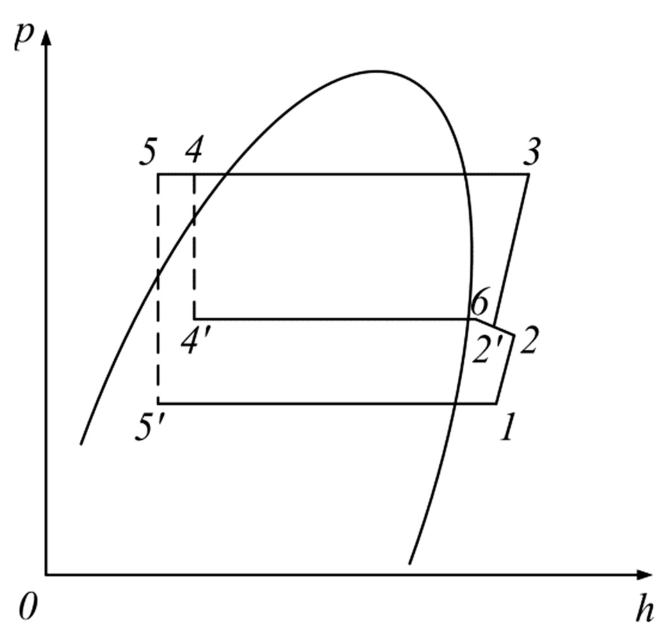

Fig. 1. The *p*-*h* graph of heat pump system cycle.

2. Description of experimental set-up

2.1. Experimental facility and procedures

The thermal cycle can be described by the vapor compression heat pump cycle, which is shown on the *p*-*h* diagram in Fig. 1. The refrigerant leaves the compressor as a high temperature, high pressure, superheated vapor condition (state 3) and enters the condenser (the double-pipe heat interchanger), where it transfers heat to water. And then the refrigerant leaves the condenser as a high pressure condition (state 4) and is divided into two parts. The first part of the refrigerant enters the economical plate heat exchanger and releases heat (state 5), and then enters the thermostatic expansion valve 1. At state 5′, it enters the evaporator as a low pressure, low temperature condition, and then enters the compressor (state 1). The second part enters the thermostatic expansion valve 2 where it expands irreversibly and adiabatically (state 4′),