Performance Comparison and Energy Saving Ratio analysis Between Absorption Heat Pump and Gas Engine-driven Heat Pump

Sheng Shang, Wei Wu, Baolong Wang, Wenxing Shi, Xianting Li*

Department of Building Science, Tsinghua University, Beijing 100084, China

Abstract

Absorption heat pump (AHP) and gas engine-driven heat pump (GEHP) have higher efficiency of heating than the boiler, but the comparison between AHP and GEHP is seldom to find. To figure out the feasibility of these two equipment, a GEHP model is established and the system performance comparison is conducted combined with the Wei Wu's research of AHP's performance. Results show that AHP's primary energy ratio(PER) is better than GEHP when the temperature is lower than about 0°C, but it is worse as the temperature is above 0°C, and the energy saving ratio of AHP and GEHP can be 45% higher than boiler when ambient temperature is 0°C. In order to show the application for the whole heating season, the energy consumption is investigated. The results show that The ESR of AHP and GEHP is 34.7% and 32.6% in Beijing compared to the gas-fired boiler, and for Shanghai is 38.1% and 39.5% respectively. Therefore, GEHP is more suitable for the warmer area and AHP is just opposite.

Keywords:Gas engine-driven heat pump; Absorption heat pump; Natural gas; Energy saving potential; Space heating

1. Introduction

Building energy consumption in China has increased rapidly in these years, and it had been over 0.8 billion tons of coal equivalent (tce) in 2012. Space heating including centralized and decentralized heating takes about 40% of total primary energy consumption[1]. The most common way of energy consuming in China is coal-fired boiler, but there are several disadvantages like low efficiency, pollutant and particulate matter emission so it lead to green house effect and serious smog problem[2]. On the contrary, the natural gas has the advantages of higher efficiency and lower pollutant emission. Gas-fired boiler can reduce 90% SO2 and 40% NOx emission compared to coal-fired boiler[3]. Besides, gas consumption in China has reached a higher level in these years, therefore, it's extremely important to figure out how to make full use of natural gas in different regions.

There are mainly four ways of the utilization of gas for space heating: gas-fired boiler, household gas fireplace, gas engine-driven heat pump(GEHP) and absorption heat pump(AHP).Since the low temperature heating is more popular, the research on GEHP and AHP has been paid much attention. Yang et al[4,5] and Zhang et al[6,7] investigated the performance of GEHP with experimental and simulation method and the results showed that the

* Xianting Li. Tel.: +86-10-62785860; fax: +86-10-62773461.
E-mail address: xtingli@tsinghua.edu.cn.

primary energy ratio(PER) of GEHP can reach 1.8 in some working conditions. Sepehr et al made the comparison of GEHP and EHP for heating[9], and Hepbasli et al compared the heating performance of GEHP and boiler[10], both the results showed that the GEHP is more energy-saving, and the energy saving ratio is more than 20% and 40% compared to EHP and gas-fired boiler, respectively. As for AHP, Wu et al has done deep research on the performance with different working pairs, refrigerant cycle, heat source(air source and ground source) and pressure boost[11,12]. Besides he also compared the heating performance and energy saving ratio with boiler in northern areas in China, and the results showed that the AHP can save40% energy than gas-fired boiler and it is a better way to substitute the boiler for heating[2].

However, there're seldom papers that compared the real performance of AHP and GEHP. Even though Zhang et al chose an AHP model with LiBr-H2O as the working pair and compared it with GEHP[13], the research is mainly focused of the average seasonal system performance. What's worse, AHP with LiBr-H2O as the working pair isn't good at heating because the crystallization problem, so that the conclusion is drawn that GEHP for heating is better than the other equipment in every region in China.

In this work, in order to compare the heating performance, the GEHP's mathematic model is established and the heating performance is validated with other researcher's experimental data. To make the heating performance comparison under different ambient temperature with other gas-consumption equipment, the AHP model established by Wei Wu is chosen[2]. Finally the energy saving ratio of GEHP and AHP in different regions has been conducted to show the feasibility of each equipment.

2. Mathematic model

In order to investigate the system performance of GEHP, the mathematic model is established. The AHP model is referred to Wei Wu's research, the mathematic model can be referred in this paper[2].

2.1. GEHP mode

The output work, gas consumption and fuel gas temperature of the engine is what we concerned, therefore some product's catalogues are referred to calculate output work, cylinder jacket heat generation and the temperature of waste gas. The rated output work of the chosen engine is 15kW.

The gas consumption and the output work are affected by engine rotation speed and load ratio referred to a product sample. And the proportion of cylinder jacket heat generation to the gas consumption is given by a model from TRNSYS (shown as Fig. 2).The temperature of exhausted gas is the fitting formula from Zhang's research[15], and the accuracy is acceptable. The equation is shown as Eqa. (1), and the parameters are shown in the Tab. 1.

$$T_{gas} = c1 + c2 \cdot RPM + c3 \cdot RPM^2 + c4 \cdot Tr + c5 \cdot Tr^2 + c6 \cdot RPM * Tr \cdot c7 * RPM \cdot Tr^2 + c8 \cdot RPM^2 \cdot Tr + c9 \cdot RPM^2 \cdot Tr^2 \quad (1)$$

[15]

Table 1 Parameters of fuel gas temperature formula in Eqa. (1).

c1	c2	c3	c4	c5
276.8	0.004527	-1.20 • 10-8	0.3176	-1.11 • 10-3
c6	c7	c8	c9	
-7.07 • 10-5	2.367 • 10 -5	4.639 • 10-9	-1.5 • 10-12	

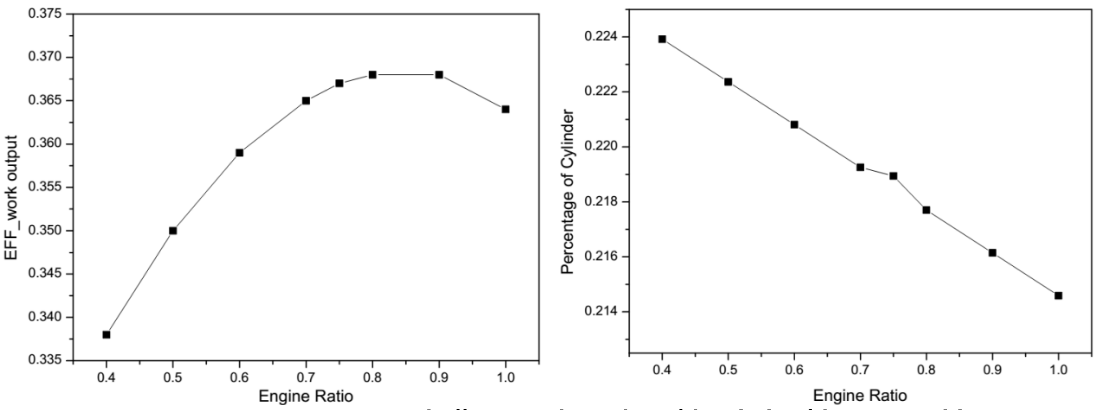


Fig. 1Output work efficiency and waste heat of the cylinder of the engine model.

For the compressor, we should calculate the refrigerant mass flow rate and work consumption. The efficiency model is chosen and the equations of volumetric efficiency and isentropic efficiency are given as follows[14]:

$$\varepsilon_{ise} = 1 - 0.04 \cdot PR \tag{2}$$

$$\varepsilon_{ise} = 0.9 - 0.0467 \cdot PR \tag{3}$$

εvol is used to calculate the mass flow rate of refrigerant using Eqa. (4), and the work consumption is calculated by the enthalpy difference of the compressor and εise(Eqa. 5).

$$m_r = \varepsilon_{vol} \cdot DISP \cdot RPM \cdot \rho / 60 \tag{4}$$

$$W = m_r \left(h_{r,cout} - h_{r,cin} \right) / \varepsilon_{ise} \tag{5}$$

For the heat exchanger such as evaporator and condenser, the lumped parameter method is chosen and the heat exchange capacity UA is given according to the heating demands. And the detail information of the heat exchanger is shown as Table 2.The heat transfer and energy balance equations are (6) to (8) and the heat exchange process is considered to be counter-flow. For the expansion valve, the process is isentropic, and the superheat and subcool degree are set to 5°C.

$$Q = m_a \cdot (h_{a,in} - h_{a,out}) \tag{6}$$

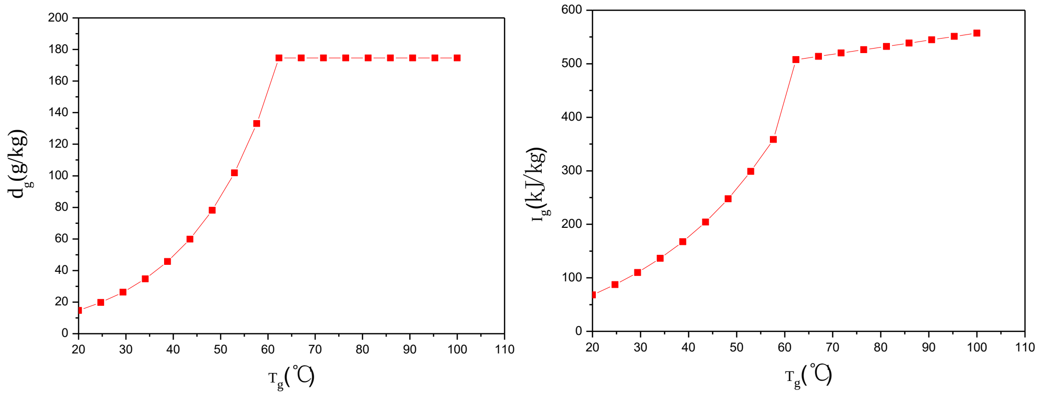
$$Q = m_r \cdot (h_{r,in} - h_{r,out}) \tag{7}$$

$$Q = UA \cdot \Delta Tm \tag{8}$$

According to the gas flow rate and excess air coefficient 1.2, the specific heat, dew-point temperature and mass flow of exhausted fuel can be calculated, and the condensing heat of the vapor in the waste gas is taken into consideration. When the temperature of exhausted fuel is lower than its dew-point, the vapor will condense and release the latent heat. And the relationship between fuel gas temperature with absolute humidity and the enthalpy is shown as Fig. 3 (a) and (b).

Table2 Information of the heat exchangers in the mathematic model.

Heat exchanger	Heating mode	
	UA(kW/K)	LMTD(°C)
Evaporator	6.4	5.14
Condenser	8	5.5
Cylinder jacket	0.18	33
Waste heat exchanger	0.06	115



(a) (b)

Fig. 2 The relationship between fuel gas temperature with absolute humidity and the enthalpy.

2.2. Model validation

Referred to some experiment data conducted by Elgendy[10], the GEHP model is validated. Elgendy built up an air-to-water GEHP platform and test different inlet temperature of condenser under the condition that the ambient temperature is 11.9℃ and the engine speed is 1300rpm. The PER of GEHP is defined as Eqa. (9):

$$PER = \frac{Q}{E} \tag{9}$$

Where Q means the heating capacity in winter and the cooling capacity in summer, kW; and E means the energy consumption at the same time, kW. The PER validation with Elgendy's experiment data is shown as Table 3, and when the condenser inlet temperature is lower, the relative error gets larger, however, the maximum relative error is within 5%.

Table2 PER Validation of GEHP with Elgendy's experiment data.

Condenser inlet temperature(°C)	Experiment	Simulation	Relative error
32	1.85	1.95	5%
33	1.83	1.9	4%
34	1.81	1.86	3%
35	1.8	1.82	1%
36	1.76	1.78	1%
37	1.73	1.74	1%
38	1.7	1.71	1%
39	1.69	1.68	-1%
40	1.67	1.65	-1%
41	1.6	1.62	1%

3. Results and analysis

In this part, the performance of GEHP is shown, and the performance comparison is conducted under different ambient temperature. Finally, the energy saving potential in different regions is investigated and the feasibility of GEHP and AHP is analyzed.

3.1. Heating performance of GEHP

After establishing the GEHP model, the heating performance of GEHP with the change of ambient temperature can be calculated and the results are shown as Fig.4. Heat generation of the condenser is increasing as the ambient temperature is rising, so as the PER is, but the heat generation of the cylinder and exhausted fuel increases a little. When the ambient temperature is 7°C, the PER of GEHP can be higher than 1.5. And the proportion of engine waste heat is 27% to the total heat generation. The absolute value of the engine waste heat generation changes a little, but the heat generation from the condenser increases a lot because the evaporation pressure is arising.

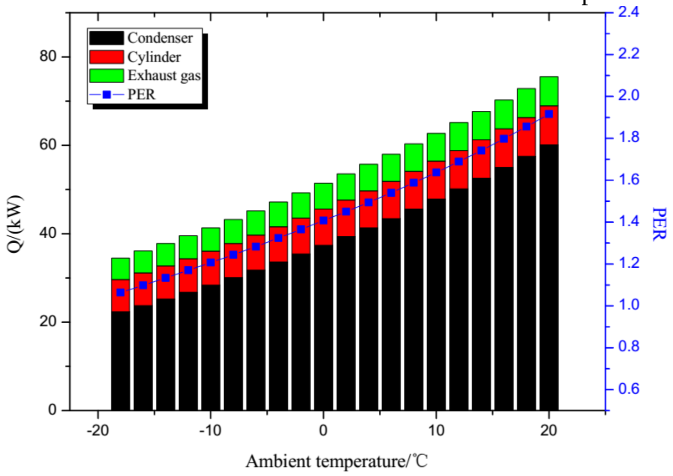


Fig. 4 Heating performance with the change of ambient temperature (engine speed is 3000rpm).

3.2. Comparison of the system performance

For the GEHP system, the supply water temperature is set to 45°C, and the engine speed is 3000rpm. And the supply water temperature of AHP is the same as the GEHP. Then the PER comparison of each equipment is shown as Fig. 5. From this figure, both AHP and GEHP have higher PER than gas-fired boiler and the difference between them is increasing speed as the ambient temperature is rising. GEHP's PER is lower than AHP when ambient temperature is lower than 0°C, but it has better system performance than AHP when the ambient temperature is higher. Therefore, AHP is more suitable for cold regions and GEHP is better for warmer areas.

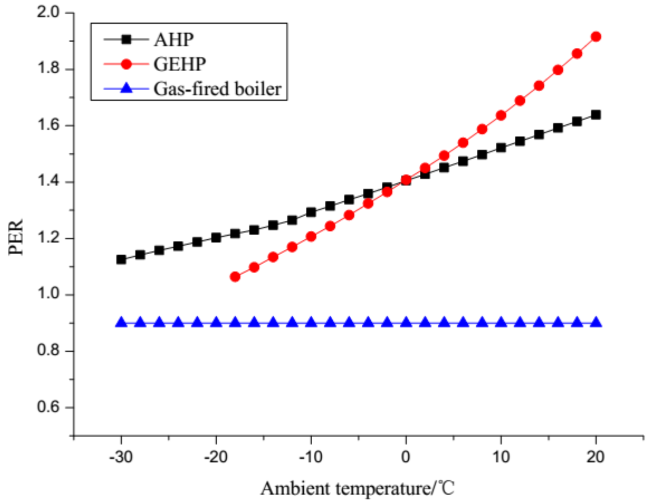


Fig. 5 Comparison of PER of each equipment with the increase of ambient temperature

3.3. Case study and application feasibility

To prove the feasibility of GEHP and AHP, the case study is conducted. The Building model is established in Beijing and Shanghai, and the hourly building load is calculated by DeST. Then the hourly system PER of GEHP and AHP is calculated by the method above. The hourly and heating-season gas consumption can be calculated by the equation (10~12):

$$Qe_i = \frac{|Q|_i}{PER_i} \tag{10}$$

$$Qe = \sum_{i=1}^{2160} \frac{Q_i}{PER_i} + \sum_{i=7297}^{8760} \frac{Q_i}{PER_i} \tag{11}$$

$$E = \frac{Qe \cdot 3600}{LCV} \tag{12}$$

Where E is the gas consumption, Nm3, LCV means the low calorific value of gas, 35000kJ/Nm3. The gas-fired boiler efficiency is set 0.9. The results of the gas consumption for the whole heating season is shown as Fig. 6. From this figure, using AHP or GEHP can save gas consumption compared to gas-fired boiler in both Beijing and Shanghai. And due to the ambient temperature, AHP consume less gas than GEHP in Beijing, but more in Shanghai. In the meantime, the ESR of AHP and GEHP is 34.7% and 32.6% in Beijing compared to the gas-fired boiler, and for Shanghai is 38.1% and 39.5% respectively. This result proves that GEHP is more suitable for the warmer areas.

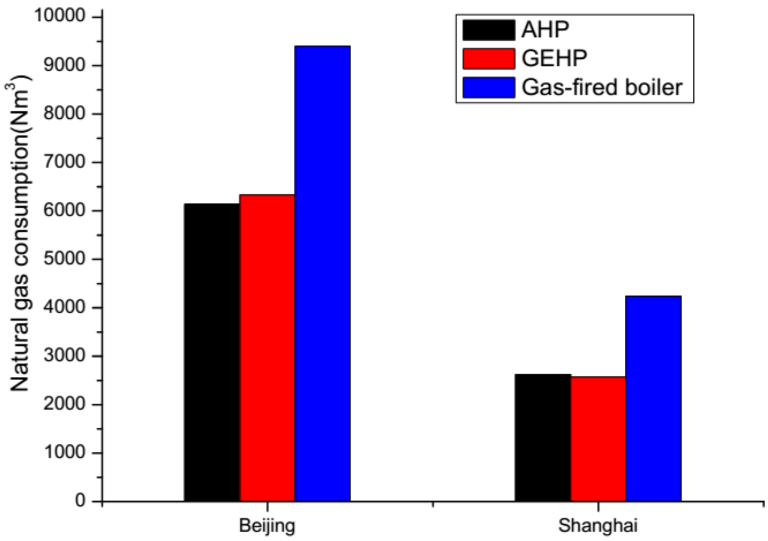


Fig. 6 Energy consumption of the whole heating season in different cities

4. Conclusion

In order to compare the heating performance, the GEHP's mathematic model is established and the heating performance comparison under different ambient temperature with other gas-consumption equipment is conducted. To analyze the energy saving potential of the GEHP or AHP, the gas consumption in Beijing and Shanghai has been investigated to show the feasibility of each equipment. The main conclusions from above analysis are as follows:

1. The GEHP has better heating performance than gas-fired boiler, and the heating PER can reach to 1.5 when the ambient temperature is 7°C, and the waste heat proportion is about 27%.
2. The heating PER of GEHP is higher than AHP when the ambient temperature is above 0°C, and the AHP is more suitable for the cold region.
3. The ESR of AHP and GEHP is 34.7% and 32.6% in Beijing compared to the gas-fired boiler, and for Shanghai is 38.1% and 39.5% respectively. And the GEHP is more suitable for the warmer places.

Acknowledgments

The authors gratefully acknowledge the support of the Innovative Research Groups of the National Natural Science Foundation of China (grant number 51521005).

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