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Evaluation method of gas engine-driven heat pump water heater under the working condition of summer

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ABSTRACT

As the current evaluation methods of gas engine-driven heat pump systems (GEHPs), primary energy ratio (PER) is incapable to evaluate the seasonal performance of gas engine-driven heat pump water heater (GEHPWH), and seasonal primary energy ratio (SPER) is too complex in procedures. An evaluation method for seasonal performance of GEHPWH should be proposed, which is both simple and accurate. This paper presents a new evaluation method named integrated primary energy ratio (IPER) based on PER and SPER. In order to test the validity of the evaluation result, experimental studies about seasonal performance of GEHPWH have been carried under the working condition of summer. Experimental results indicated that the calculation result of IPER is relatively accurate compared with the calculation result of SPER, while the experimental and calculation procedures of IPER are much simpler than that of SPER. The seasonal performance of GEHPWH calculated with SPER is 2.09 in summer, and the IPER value of GEHPWH in the same condition is 2.01, the error compared with SPER is only 3.7%.

1. Introduction

Gas engine-driven heat pump water heater (GEHPWH) [1–6], usually consists of a vapor compression heat pump with an open compressor driven by a gas engine, with the advantages of efficiency, energy conservation, environmental protection, easy to be modulated, etc. What is more, it would meet the needs of supplying cooling in summer and supplying heating in winter for buildings, as well as supplying hot water at the same time. Compared with electric-driven heat pump water heater (EHPWH), there are two distinguished advantages of GEHPWH: (1) GEHPWH has a higher water outlet temperature with recovering the waste heat released by the engine cylinder jacket and exhausted gas. (2) It is easy to modulate the engine speed by adjusting the amount of gas input. Therefore, GEHPWH has a more excellent performance than EHPWH. In addition, GEHPWH even can get rid of the dependence on power grid with self-supplied electric system. Because of the advantages above, there is no wonder that GEHPWH has been paid increasing attention in resent years.

A proper evaluation method is necessary for research and developing the performance of GEHPWH. Currently, the main evaluation methods of GEHPWH performance are the primary energy ratio (PER) [7–11] and seasonal primary energy ratio (SPER) [12]. However, it is not enough to take the method of PER merely to evaluate the seasonal performance of GEHPWH, resulting from that the instantaneous performance of GEHPWH system is variable with the ambient air temperature changing. Although utilizing the evaluation method of SPER is relatively accurate, this method is too complex in procedures. Before evaluating the GEHPWH with SPER, it is necessary to test PER value of this system at each ambient air temperature points. American Refrigeration Institute [13] have developed an evaluation method of integrated partial load value (IPLV) to evaluate the water chillers, it is not only accurate but also convenient, while unfortunately it is not suitable to the GEHPWH performance evaluation.

There is a lack of an evaluation method which can evaluate the seasonal performance of GEHPWH both accurately and conveniently. Thus, integrated primary energy ratio (IPER) as present work has been carried out with the aim of putting forward a better evaluation method of seasonal performance of GEHPWH, basing on the previous evaluation method of PER and SPER. In this communication we have given mathematical equations and details explanation of IPER. In order to test the validity of evaluation result of IPER, experimental studies about seasonal performance

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Nomenclature

T	ambient air temperature (°C)
Q_c	cooling capacity (kW)
Q_{hw}	heating capacity for hot water (kW)
Q_w	energy demand (kW)
Q'_c	the total cooling load in summer (kJ)
Q'_{hw}	the total heating load for hot water in summer (kJ)
Q'_w	the total energy consumption in summer (kJ)
h	the weighted number
Q_{cj}	cooling capacity at a certain temperature (kW)
Q_{hwj}	heating capacity at a certain temperature (kW)
Q_{wj}	energy demand at a certain temperature (kW)
H_j	the number of hours at a certain temperature

Greek symbols

α	three coefficient
β	quadratic term coefficient
x	a coefficient
ε	constant term
λ	weight ratio of number of hours

Subscripts

i	integer variable pointer, $i \in [1,4]$
k	integer variable pointer, $k \in [2,4]$
n	integer variable pointer, $n \in [1,4]$
j	integer variable pointer, $j \in [1,16]$

of GEHPWH have been carried out under the working condition of summer. The calculation results of seasonal performance of GEHPWH have been compared between the evaluation method of IPER and the evaluation method of SPER.

2. Gas engine-driven heat pump water heater

2.1. System description

Gas engine-driven heat pump water heater (GEHPWH), driven by the gas engine, is consisted of three subsystems, including heat pump system, waste heat recovery system and water loop systems.

Heat pump system is a type of water to water heat pump under the working condition of summer, with an open type compressor, a condenser, an evaporator and an expansion valve. Refrigerant R134a is used as the working fluid in this heat pump system. The return chilled water from air conditioning system is the heat source of this heat pump system.

Waste heat recovery system is mainly made up of a cylinder jacket heat exchanger, an exhaust gas heat exchanger and a waste heat exchanger. The waste heat released by engine cylinder jacket and exhaust gas is recovered by cylinder jacket heat exchanger and exhaust gas heat exchanger, respectively. Water loop system consists of chilled water loop system and hot water loop system. Return chilled water from air conditioning system cooled in the evaporator supplies cooling capacity for buildings through air conditioning system. Thus, the chilled water tank and related terminal equipment of the air conditioning system have been used to supply cooling capacity for buildings.

2.2. Operating principle

The schematic diagram of GEHPWH is shown in Fig. 1 Under the working conditions of summer, as the supplement of hot water, the user's demand of cooling capacity supply for space could be satisfied at the same time. Plate heat exchanger C1 and plate heat exchanger C2 work as the evaporator and a condenser of the heat hump system, respectively. The heat of return chilled water from air conditioning system is absorbed by evaporator and then the chilled water supplies cooling capacity for space. Firstly, tap water enters into the condenser of the heat pump system to absorb the condensing heat; secondly, it is heated by the waste heat in the hot water tank until meeting the required temperature.

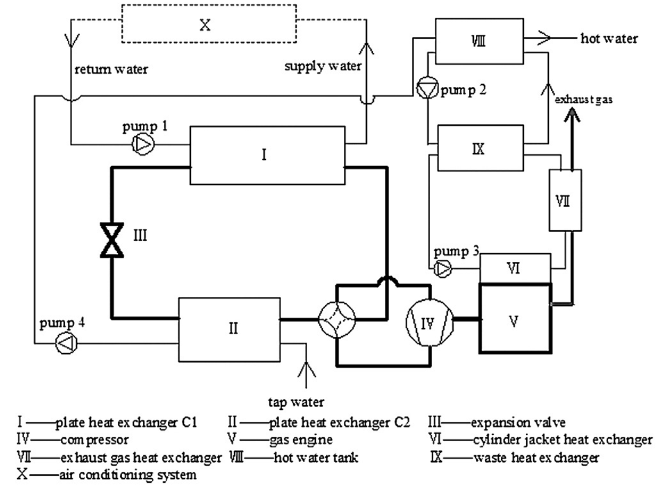

Fig. 1. Schematic diagram of gas engine-driven heat pump water heater.

3. Evaluation method of IPER

3.1. Performance characteristics of GEHPWH

Variations of cooling capacity, heating capacity and energy demand with the ambient air temperature are shown in Fig. 2, which indicates that cooling capacity, heating capacity for hot water and energy demand are all increase as the ambient air temperature increases, while tendencies are different.

According to Fig. 2, the tendencies of cooling capacity, heating capacity for hot water and energy demand vary with the ambient air temperature. Because of the cooling load of the buildings increasing with the ambient temperature increasing, cooling capacity of GEHPWH has to increase through improving the rotating speed of engine to meet the needs of cooling capacity for buildings. In addition, volumetric flow rate of chilled water in the air conditioning system was changing during the experiments in order to fix the

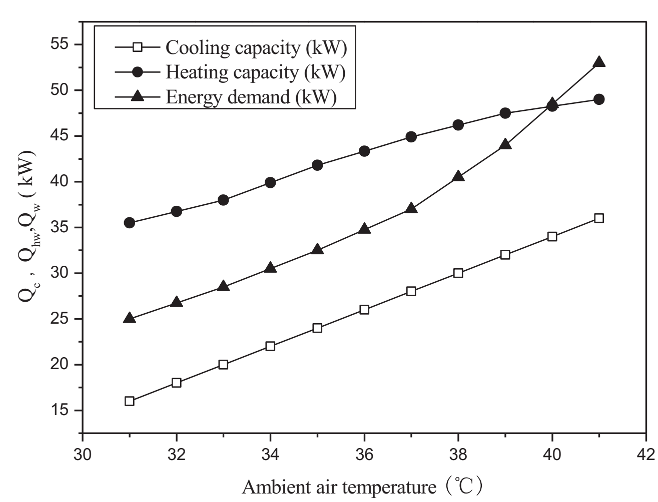

Fig. 2. Performance characteristics of gas engine-driven heat pump water heater.