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Research Paper

A study on the performance of a newly designed heat pump calorimeter

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HIGHLIGHTS

- The heat pump calorimeter is the testing facility to investigate the performance of a heat pump.
- The heat pump calorimeter consumed much more energy than heat pump.
- The newly designed calorimeter could save energy greatly rather than the conventional system.
- It is recommended to adopt small refrigerator for maximizing energy saving rate.

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ABSTRACT

The heat pump calorimeter is the testing facility to investigate the performance of a heat pump using standard test conditions obtained from domestic or international standard organizations. Conventionally, the calorimeter consumes so much energy in order to control and maintain the entering water temperature test conditions of the water-to-water heat pump unit. To minimize this energy, a newly designed calorimeter for the water-to-water heat pump was proposed in this study. Experiments were conducted in both heating and cooling modes with variation in capacity and COP of heat pump unit. In heating mode, entering water temperature test conditions of 40 °C and 5 °C were set for the indoor heat exchanger and outdoor heat exchanger of the heat pump unit respectively. In cooling mode, entering water temperature of 25 °C and 12 °C were set for the outdoor heat exchanger and indoor heat exchanger of the heat pump unit respectively. The analysis of the test results from the experiment showed that the newly designed calorimeter was able to save about 75% or more of the total power consumption comparing with the conventional calorimeter for all heat pump capacity and COP that were investigated.

1. Introduction

Energy is a key component in the development of modern society. It promotes economic growth and improves the quality of life. The escalation in worldwide population has contributed to the rising energy consumption, and demand levels are estimated to be 45% higher in 2030 than current levels [1]. In the field of heating, ventilation and air conditioning (HVAC) systems, heat pumps offer the most energy-efficient way to provide heating and cooling in many applications [2]. This is because they have the ability to utilize renewable energy sources and also impact the environment positively than the conventional burning of fossil fuels [3]. Several heat pump types are in existence; some require external mechanical work while others require external thermal energy. Commercial heat pumps based on the vapour compression cycle or the absorption cycle are operational in several applications in various industries. New heat pump technologies such as the adsorption cycle or the chemical reaction cycle are emerging rapidly, even though they have yet to find major industrial applications [4].

Any heat pump, either for domestic or commercial purpose comes with a set of performance data. This data provides information about the heat pump such as reliability and performance to serve as reference point for end users. However, the heat pump should be tested, rated and certified to estimate the performance before it is distributed. The testing and rating of heat pumps are strictly guided and regulated by standard test conditions provided by international and domestic standard organizations [5–7]. Conventionally, the heat pump testing facility makes use of a calorimeter [8], on the basis of energy balance method in rating and certifying the heat pump [5,9]. The ideal function of the heat pump calorimeter is to control and keep the standard test conditions constant during the testing period while serving as the heat sink and heat source for the heat pump. Heat is transferred to

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Nomenclature

COP	coefficient of performance	ID HX	indoor heat exchanger
EWT	entering water temperature	LWT	leaving water temperature
HR HX	heat recovery heat exchanger	OD HX	outdoor heat exchanger

the evaporator of the heat pump by the heating system of the calorimeter and absorbed from the condenser of the same heat pump by the refrigeration system of the calorimeter. Hence the energy consumption of the calorimeter which incorporates the energy used by the heater and refrigeration unit is much higher than that of the heat pump itself.

Several research studies have focused on ways to improve the performance of heat pump systems. For instance, the incorporation of a heat-driven ejector to the heat pump has improved system efficiency by more than 20% [10–12]. Also, the development of better compressor technology has the potential to reduce energy consumption of heat pump systems by as much as 80% [13–16]. The evolution of new hybrid systems has also enabled the heat pump to perform efficiently with wider applications [17–20]. Renedo et al. [21] studied on the energy efficiency of reversible water-to-water heat pumps and proposed a system that reduces the annual energy consumption for any annual thermal demand of the system. Janghoo et al. [22] optimized the design of HVAC systems to minimize primary energy demand. Neksa et al. [23] studied on the characteristics, system design and experimental results of a CO_2-heat pump water heating system. The energy consumption of the system reduced by 75% when compared to electrical or gas fired systems. Bahri and Kodal [24] proposed appropriate functions consisting of investment and energy consumption costs for endo-reversible refrigerators and heat pumps to find optimal design conditions. Moatassem et al. [25] also developed an optimization model to minimize energy consumption and carbon emission of aging buildings by implementing sustainability measures such as efficient HVAC systems and renewable energy systems.

However, due to the high energy consumption of the heat pump calorimeter, it is also of great significance to adopt efficient methods to monitor and control the energy in order to improve system performance. Rodolfo et al. [26] concluded that, the performance of a calorimeter can be improved by using a predictor-based controller known as dead-time compensator after analyzing a model data and a real experimental result. Schroder et al. [27] developed a flow calorimeter which is able to eradicate the guess-work used in determining the specific heat capacity of geothermal water flow.

Research work on calorimeter for testing heat pumps is very rare in literature. This study focuses on calorimeter for testing the performance of a water-to-water heat pump unit. The conventional calorimeter is used to test the performance of a water-to-water heat pump unit. A newly designed calorimeter is then proposed to execute the same tests. The purpose is to reduce the energy used in the conventional calorimeter. The energy consumption analysis of the newly designed calorimeter is then compared to that of the conventional calorimeter.

2. Experimental setup and test procedure

2.1. Experimental setup

The calorimeter set up in this study is a testing facility used to investigate the performance of a water-to-water heat pump unit as shown schematically in Fig. 1. Conventionally, the heat pump calorimeter has two compartments; the indoor side and outdoor side. Each side of the calorimeter is controlled separately because there is no connection between the indoor and outdoor heat exchanger of the heat pump. Two secondary fluid loops, one for each side, are used to connect the calorimeter to the heat pump unit. One fluid loop connects the indoor side of the calorimeter to the indoor heat exchanger (ID HX) of the heat pump. The other loop connects the outdoor heat exchanger (OD HX) of the heat pump to the outdoor side of the calorimeter. The secondary fluid used in the experiment is mainly water with a 40% concentration of ethylene glycol solution. Each side of the calorimeter is equipped with a constant temperature bath (CTB), a refrigeration unit and electric heater. The refrigeration unit and electric heater are used to set up and maintain the temperature of the secondary fluid located inside the CTB based on standard test conditions [5]. The setting temperature of the secondary fluid in the CTB is used as the entering water temperature (EWT) to the heat exchanger of the heat pump test unit. There is also a volumetric flow meter and circulation pump on each side of the calorimeter as shown in Fig. 1. The flow meter is used to maintain the flow rate of the secondary fluid according to the capacity of the heat pump unit while the circulation pump is used to transport the secondary fluid from the CTB through the heat pump heat exchanger to the refrigerator, electric heater and back to the CTB. In the proposed newly designed calorimeter, a heat recovery heat exchanger (HR HX) unit is used to connect the indoor side flow loop to the outdoor side flow loop as shown in Fig. 1. Hence heat can be transferred from one side of the calorimeter to the other side.

As the heat pump capacity change, the COP also change. It is therefore impossible to analyze the calorimeter's performance on experimental basis by using heat pumps with different capacities and COPs. Hence a heat pump simulator is developed to imitate the variation of heat pump capacity and COP separately. The actual heat pump unit consists of an ID HX, OD HX, a compressor, an expansion valve and a four-way valve as in Fig. 1. However, the heat pump simulator as shown in Fig. 2 consists of two plate type heat exchangers; ID HX and OD HX, two constant temperature water baths and two circulation pumps. The capacities of the ID HX and OD HX are controlled separately by using the temperature and flow rate of each heat pump constant temperature water bath line connected to the ID HX and OD HX. The constant temperature water bath line is used to replace the refrigerant line in an actual heat pump unit. The simulator can realize the change of COP and capacity separately.

The experimental rig as shown in Fig. 3 which consist of the heat pump simulator section and the calorimeter section is therefore used for testing the performance of a water-to-water heat pump unit using standard test conditions based on Refs. [28,29] in both conventional and newly designed heat pump calorimeters. The two needle valves located on the indoor side flow line are used to control the amount of heat transfer rate in the HRHX between the indoor side flow and outdoor side flow loops. Temperature measuring devices such as resistance thermal detectors (RTDs) and T-type thermocouple sensors are used to measure temperatures in the experimental set up. The T-type thermocouple and RTD sensors have uncertainty of ±0.1 °C of reading scale. The volumetric flow meters that are used to measure the flow rate of the secondary fluid also have uncertainty of ±0.1% of full scale.