World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:6, No:7, 2012

A Comparative Study of Vapour Compression Heat Pump Systems under Air to Air and Air to Water Mode

Kemal Çomakli, Uğur Çakir

***Abstract*—**This research evaluated and compared the thermodynamic performance of heat pump systems which can be run under two different modes as air to air and air to water by using only one compressor. To achieve this comparison an experimental performance study was made on a traditional vapor compressed heat pump system that can be run air to air mode and air to water mode by help of a valve. The experiments made under different thermal conditions. Thermodynamic performance of the systems are presented and compared with each other for different working conditions.

***Keywords*—**Air source heat pump, Energy Analysis, Heat Pump

I. Introduction

THE climatic conditions of the region are one of the prime factors, which effect the development of the plant and the economics of heat pump system because of that air is the most common used heat source for heat pump systems.One of the systems which can be used for heating and cooling applications in buildings is heat pump. Due to their high energy efficiency and reliability they can be used for many thermal applications. General properties of the heat sources used at heat pumps are very important to have more benefit and to reach more effective systems. The major problem with the air source system is frosting, which occurs especially in humidity climates when the temperature falls below 5^{o}C [1].

The technical and thermophysical characteristics of heat source or heat sink useddirectly have a big important role on the technical andeconomic performance of heat pumps. The heatsources and heat sinks which are commonly used orpreferred in practical applications are ambient air, lakewater, river water, soil, rock, and wastewater, affluentand exhaust air.The heat pumps which use water as heat source are haveattractive performance characteristics when designed and installed properly. Additionally those systems areconsidered a viable alternative to conventional coolingand heating systems. They offer many performanceadvantages over air-source heat pumps due tooutstanding heat transfer properties of water and muchmore favorable temperatures of river or lake water.

The advantages and disadvantages of water-source heat pump systems are discussed previously by several researchers [2]-[6]. A simple heat pump system consists of four main components, which are compressor, two heat exchangers condenser and evaporator) and expansion valve, in addition to these components, many auxiliary components may be used on heat pumps such as valves, thermostats, some measurement tools, pumps, fans, or extra heaters.

Comakli K. is with Mechanical Engineering department at Atatürk University,Erzurum, Turkey (phone: +90 442 231 48 49; fax: +90 442 231 48 45; e-mail: kcomakli@ atauni.edu.tr).

Cakir U.,is with Mechanical Engineering department at Bayburt University, Bayburt, Turkey. (phone: +90 458 211 11 53-3211; fax: +90 458 211 11 72; e-mail: ucakir@ bayburt.edu.tr).

For heating purposes, they can be divided into basic types, determined by the source and the destination of the heat and the medium that the heat pump uses to either absorb or reject the heat in each of these locations.

At either of the heat exchangers the heat transfer media can be either liquid (water, or often a glycol mixture) or air; sometimes it is a combination of the two. In describing the type of heat pump, generally the heat source is generally provided first, followed by the destination or heat sink. The main variants in common use are; air to air, water to water, water to air, air to water, ground to water, ground to air types.

Thermal characteristics and the types of the used heat sources and heat sinks are very important for the performance of heat pumps. Commonly used heat sources and heat sinks are ambient air, exhaust air, lake water, river water, ground water, earth, rock, wastewater International Conference on Water, Energy and Environment 2011 and effluent. Most used heat sources and heat sinks on heat pump systems are ambient air and water around the world. Ambient air is a widely available and a free heat source for heat pumps. However, the thermodynamic performance of air source heat pump systems decrease depend on the decreasing the temperature of air in the heating seasons and increasing the temperature of air in cooling seasons. Because of the heat transfer properties of water, water source heat pump systems offer some performance advantages over heat pump systems which use air as heat source [7].

Many studies and investigations have reported in the open literature on different types of heat pumps and on comparison of them experimentally or by simulations, according to their heat sources, heat sinks, and the place they are being used, the refrigerant used as working fluid, structures and capacities of components i.e. [8]-[13]. For example; Swardt and Meyer [8] reported that, the performance of a reversible ground-source heat pump coupled to a municipality water reticulation system was compared experimentally and with simulations to a conventional air-source heat pump for space cooling and heating. The experimental and simulated comparisons of the ground source system to the air source system were conducted in both the cooling and heating cycles. The results showed that, the utilization of municipality water reticulation system a heat source/sink is a viable method of optimizing energy usage in the air conditioning industry, especially when used in the heating mode. Especially at low ambient air temperatures ground-source heat pumps have significant capacity (24 per cent) and efficiency improvement (20 per cent) over air-source heat pumps. Petit and Meyer [9] made a comparison of the economic viability in South Africa of horizontal-ground source systems and air-source systems. In order torealize this aim, monthly heating and cooling capacities and coefficients of performance for both systems were determined. The payback period, net present value, and internal rate of return of systems were calculated. It was concluded that, ground source systems are more viable than air source systems.

Urchueguia et al. [10] made an experimental comparison between a ground coupled heat pump system and a conventional air to water heat pump system, focusing at the heating and cooling energy performance. For whole climatic season the results obtained showed that the geothermal system saves, in terms of primary energy consumption a 43 ±17% of the energy consumed by the conventional one when the system is working in heating mode, and a 37 ±18% win cooling mode when the system is working in cooling mode. The results also demonstrated that, a ground source heat pump system is viable and energy efficient alternative to conventional systems for heating and cooling applications in the South European regions. KavakAkpınar and Hepbaşlı [11] reported that; they made a comparative study on exergetic assessment of two ground-source (geothermal) heat pump systems for residential applications. The study dealt with the exergetic performance evaluation of two types of ground source heat pump systems installed in Turkey based on the actual operational data. The first one is a ground source heat pump system designed and constructed for investigating geothermal resources with low temperatures, while the other one is a ground source heat pump with a vertical ground heat exchanger. Esen et al. [12] made a study which reported a techno-economic comparison between a ground-couple heat pumps system (GCHP) and air coupled heat pump (ACHP) system. The experimental results were obtained from June to September in cooling season in 2004. The test results indicated that system parameters can have an important effect on performance and that GCHP systems are economically preferable to ACHP systems for the purpose of space cooling.

Bakirci et al. [13] made a study in order to investigate the performance of the solar-ground source heat pump system in the province of Erzurum having cold climate. The COP of the heat pump and the system were found to be in range of 3.0-3.4 and 2.7 to 3.0, respectively. It is also claimed that; the system investigated could be used for residential heating in the province of Erzurum being a cold climate region of Turkey.

II. Experimental Set up and Analysis

Fig. 1 shows the schematic diagram of the experimental apparatus. The system was originally designed for operating with R22. The main components of the system are a scroll compressor, an air cooled evaporator, an air cooled condenser, a water cooled condenser, thermostatic expansion valve, and the other elements like measurement and control equipment. In addition electrical air and water heaters are used in order to keep the temperature of air and water passing into the evaporator and condensers at the desired levels. Two electrical fans are used to circulate the air on the evaporator and condenser which is air cooled. First, the system was charged with 15 Bar R22 while all the valves were in opened position under the temperature of outdoor air and then system was run in wanted heat pump mode by closing interested valves. When the running mode wanted to be changed, all of the valves were opened and waited for one day to obtain equal spreading of refrigerant in the system for every mode. Temperature and pressure values in the key-point of the plant, as shown in Fig. 1, were continuously monitored in order to check the achievement of steadystate conditions.

Usually, the start-up time required about 1 hour. After each experimental run, the raw data which consist of temperatures from the thermocouples, pressures from the manometers, air flow rates from the anemometer, and refrigerant flow rate from the flow meters, water flow rates from the rotameters, compressor input current and voltage from the ampermeter were recorded.

The tests were performed under laboratory conditions, during the air temperature was about 20-22^{o}C, and the relative humidity was about 40-60%. The tests were made under the following order for four running mode; first air to air mode, secondly air to water mode, tests were completed. Each experiment was repeated at least three times under same conditions at different times. When all tests were made and completed for each running mode, the experimental setup was closed and waited about two days with opening all valves on it before starting the tests for another running mode. First, the temperature degree and flow rate of the condenser fluid were fixed to the constant values; 20^{o}C- 1.2 kg/s for air, 20^{o}C- 0.15kg/s for water. And then the experiments were performed at five different temperature levels for five different flow rate values of evaporator fluid. For example first, the flow rate of evaporator air adjusted to a constant value and the tests were performed for five different evaporator fluid temperatures and then the same procedure was applied for other experiments.

The numerical values of the evaporator air temperatures and flow rates are presented in Table 1 for two heat pump tests. All of the measured values which consist of temperatures from the thermocouples, pressures from the manometers, compressor input power from the wattmeter, and flow rates of the fluids used on the system from the flow meters, rotameters and anemometers were used for determining the thermodynamics performances of two heat pump modes to achieve the aim mentioned previously. Mass and energy balances are employed to determine the heat input, and energy efficiencies. From the measured parameters; the heat delivered by the condenser to the air or water is calculated by;

$$Q_{cond-air}=m\ C_a\ (T_{a-out} - T_{a-in}) \quad (1)$$

$$Q_{cond-w}=m\ C_w(T_{w-out} - T_{w-in}) \quad (2)$$

The heat extracted by the evaporator from the air is calculated by;

$$Q_{evap-a}=m\ C_a(T_{a-out} - T_{a-in}) \quad (3)$$

The power input to the compressor is calculated by;

$$W_{comp\ elec} = \sqrt{3}Cos(\emptyset).U.I.W \quad (4)$$

Where U, I and Cos (θ) are voltage (V), current (A) andpower factor, respectively. The coefficient ofperformance (COP) for any heat pump and system is calculated as seen below.

$$COP_{HP} = \frac{\dot{Q}_C}{\dot{W}_{comp,elec}} \quad (5)$$

$$COP_{system} = \frac{\dot{Q}_{Cond}}{\dot{W}_{comp\ elec}+\dot{W}_{Fans}} \quad (6)$$

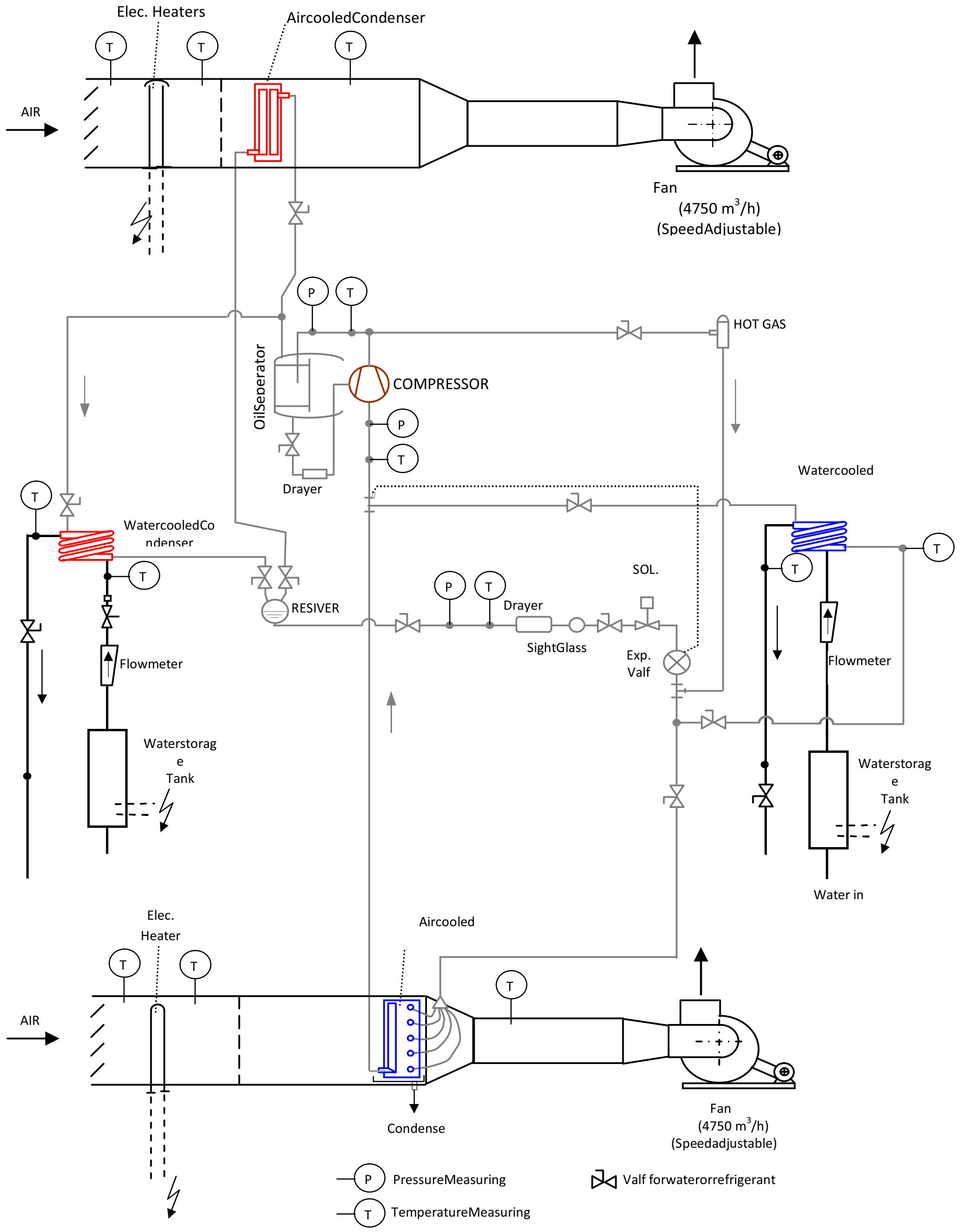

Fig. 1 Experimental system

TABLE I
LEVELS OF PARAMETERS

Parameter	Fluid	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Mass flow rate (kg/s)	Cond/Evap. Air	0.41	0.71	0.83	1.1	1.2	---
	Cond. Water	0.100	0.110	0.125	0.139	0.15	----
Temperature (°C)	Evap. Air	20	22	26	28	30	32

III. RESULT

Two different heat pump systems those run on the same experimental setup, have same heating capacity, use just one compressor, controlled by the same control equipments and the same measurement system are analyzed and compared experimentally. They are compared with each other by using energy balances-first law of thermodynamics in this study.

All of the experiments were performed under the same conditions as the air temperature and air humidity ratio in the laboratory. Within the scope of the study presented here; COP of heat pump types are evaluated, discussed and compared as the results of this paper. Differences of energetic performance of two different heat pump types according to the increasing rate of temperature and flow rate of the fluid used as heat source is expressed and compared.

Figure 2 and 3 shows the change of COP values of two heat pump units and systems according to the increasing rate of temperature of the air as heat source. As seen on the Figure 2, the heat pump unit which has the maximum COP value is air to air type. It is known that COP of heat pumps increases when the temperature of heat source increases. As seen on the related figures, performances of the two heat pumps increase when the evaporator air temperature increase.

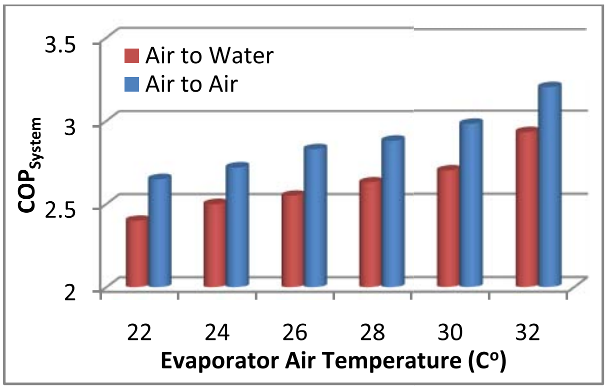

Fig. 2 COP change of systems versus increasing of evaporator fluid temperature

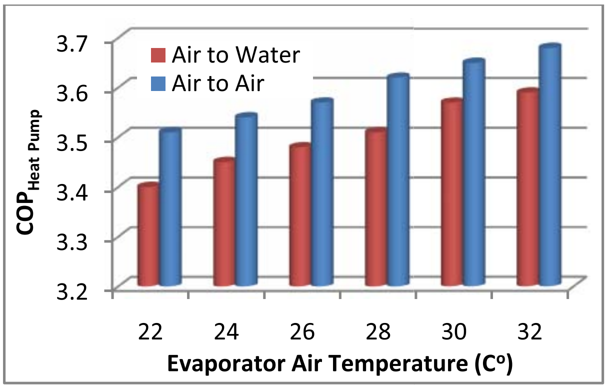

Fig. 3 COP change of heat pumps versus increasing of evaporator fluid temperature

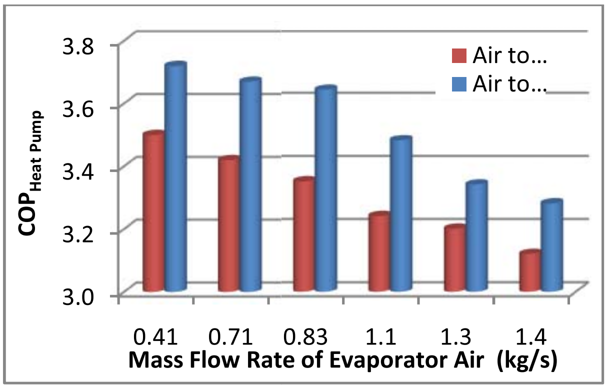

Fig. 4 COP change of heat pumps versus increasing of mass flow rate of evaporator fluid

IV. CONCLUSION

There are various studies on comparison of different heat pump types. The comparisons made between the systems, installed at different places, used for different aims, use different refrigerants as working fluid, run and tested under different conditions, have different heating capacities or have different specifications. In this study, an experimental multifunctional heat pump setup was designed to make a comprehensive comparative investigation for two different heat pump types; they have same heating capacity and same specifications. The direction of refrigerant fluid used in the system can be easily changed between the condensers and evaporator with the help of valves. In this way the designed heat pump experimental setup can be operated in different modes. Heating capacity of each heat pump mode is equal under the same conditions and can be adjusted by changing the flow rate and temperature levels of the fluid used as heat source and sink. Only one measurement system was used to get data for all heat pump types and all experiments.

The temperature degree of heat source has a big importance for using heat pumps efficiently. The heat pump units are designed for the various thermal applications have specific properties in general and therefore they are unique setups. In summary, they provide high levels for comfort, make significant reductions in electrical energy consuming and they are friendly systems for the nature. As seen on the figures in the results previously, COP of the air to air heat pump is higher than COP of the air to water heat pump in generally. The COP values of two heat pumps are affected from the increasing of evaporator air temperature. COP of the heat pumps decrease, when the mass flow rate of the evaporator air increases.

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