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An experimental exergetic comparison of four different heat pump systems working at same conditions: As air to air, air to water, water to water and water to air

Uğur Çakır [a,*], Kemal Çomaklı [b], Ömer Çomaklı [b], Süleyman Karslı [c]

[a] Department of Mechanical Engineering, Bayburt University, 69000 Bayburt, Turkey
[b] Department of Mechanical Engineering, Atatürk University, 25240 Erzurum, Turkey
[c] Department of Energy Engineering, Atatürk University, 25240 Erzurum, Turkey

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In this study, we designed a multifunctional heat pump system using just one scroll compressor and which can be run in four different modes, namely air to air, air to water, water to water and water to air, in order to make an experimental energetic and exergetic performance comparison. Experimental system consists of two condensers and two evaporators and uses R22 as working fluid. One of the evaporators and condensers uses water and the others use air as heat source/sink. Heating capacities of four heat pump types are equal to each other. It is realized by adjusting the mass flow rate and temperature level of external fluid of condenser. Results show that the heat pump unit which has the maximum COP (coefficient of performance) value is water to air type with 3.94 and followed by water to water type with 3.73, air to air type with 3.54 and air to water type with 3.40. Ranking of four heat pump types with respect to their mean exergy efficiency is as follows; water to air type with 30.23%, air to air type with 30.22%, air to water type with 24.77% and water to water type with 24.01%. Exergy destruction rates of the systems were investigated in this study and the results revealed that the heat pump type which has the maximum exergy destruction is air to air type with 2.93 kW. The second highest one is air to water type with 2.84 kW. The third highest one is water to air type with 2.64 kW and last one is water to water type with 2.55 kW. It is understood that the temperature of the evaporator external fluid affects the exergetic efficiency of the system more than the mass flow rate. In contrast to the previous, the dominant parameter which has more important effect on the exergy destruction of the heat pump unit is the mass flow rate of evaporator external fluid.

1. Introduction

Efficient energy utilization is one of the foremost issues in the world for the environmental and ecological protection in these days. It has become a concern because of environmental and energy problems like global warming, the depletion of conventional energy sources like fossil fuels and the increasing cost of energy [1]. Additionally, the big proportion of energy used in the world is consumed at heating and cooling applications in the residential and other buildings or in industrial plants. According to the recent studies, the energy used for residential and construction activities make up about 40% of the world's total energy consumption and heating and cooling applications have a key role in it [2]. Efficient energy use, including waste heat recovery and applications of renewable energy, can reduce carbon dioxide emission and global warming.

The systems of solar water heating and solar source heat pump provide a new and clean way of heating buildings in the world. Therefore, these systems can be used to minimize environmental impacts and air emission. They offer the most energy-efficient way to provide heating and cooling in many applications, as they can use renewable heat sources in our surroundings [3].

One of the heating setups which offer more economic and more efficiently heating applications is heat pump system which promises means of reducing the consumption of fossil energy resources, and hopefully the cost of delivered energy for residential heating/cooling Heat pumps are advantageous and widely used systems in many applications due to their high utilization efficiencies compared to conventional heating and cooling systems. Those systems first emerged in 1940–1950s and have some advantages

* Corresponding author. Tel.: +90 458 211 11 53x3211; fax: +90 458 211 11 72.
E-mail addresses: ucakir@bayburt.edu.tr, ugurcakir52@hotmail.com (U. Çakır).

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Nomenclature

Hz	hertz
HP	heat pump
$\dot{Q}_{con-air}$	the heat energy given to the air from air cooled condenser (kW)
$\dot{Q}_{con-water}$	the heat energy given to the water from water cooled condenser (kW)
$\dot{Q}_{evap-air}$	the heat energy given to the refrigerant from air at air heated evaporator (kW)
$\dot{Q}_{evap-water}$	the heat energy given to the refrigerant from water at water heated evaporator (kW)
$\dot{W}_{Comp\ elec}$	the electrical energy consumed by compressor (kW)
U	voltage (V)
I	current (A)
$\cos(\varphi)$	power factor
COP_{HP}	coefficient of performance of heat pump
$\dot{Q}_{Cond}$	heat energy that given to the space heating fluid from refrigerant at condenser (kW)
E	energy (kW)
Ex	exergy (kW)
ex	specific exergy (kJ kg^{-1})
$\dot{E}_{in}$	rate of energy inlets to the system (kW)
$\dot{E}_{out}$	rate of energy outlets from the system (kW)
$\dot{E}x_{in}$	rate of exergy inlets to the system (kW)
$\dot{E}x_{out}$	rate of energy outlets from the system (kW)
$\dot{E}x_{dest}$	rate of the exergy destruction (kW)
$ex_{r,w}$	the specific exergy of refrigerant or water (kJ kg^{-1})
ex_{air}	the specific exergy of air (kJ kg^{-1})
h	enthalpy (kJ kg^{-1})
h_0	enthalpy at dead state (kJ kg^{-1})
T	temperature (°C)
$T_{ca\ in}$	temperature of cooling air inlets to condenser (°C)
$T_{ca\ out}$	temperature of cooling air outlets from condenser (°C)
$T_{cw\ in}$	temperature of cooling water inlets to condenser (°C)
$T_{cw\ out}$	temperature of cooling water outlets from condenser (°C)
$T_{ea\ in}$	temperature of heating air inlets to evaporator (°C)
$T_{ea\ out}$	temperature of heating air outlets from evaporator (°C)
$T_{ew\ in}$	temperature of heating water inlets to evaporator (°C)
$T_{ea\ in}$	temperature of heating water outlets from evaporator (°C)
T_0	temperature at dead state (°C)
s	entropy (kJ kg^{-1})
s_0	entropy at dead state (kJ kg^{-1})
Cp_a	specific heat of air (kJ kg^{-1} K^{-1})
Cp_{vapor}	specific heat of vapor (kJ kg^{-1} K^{-1})
ω	specific humidity ratio of air
ω_0	specific humidity ratio of air at dead state
R_{air}	gas constant of air (kJ K^{-1} kg^{-1})
P	pressure (kPa)
P_0	pressure at dead state (kPa)
$\dot{m}_a$	mass flow rate of cooling or heating air at condenser or evaporator (kg s^{-1})
$\dot{m}_w$	mass flow rate of cooling or heating water at condenser or evaporator (kg s^{-1})
$\dot{m}_{vapor}$	mass rate of vapor in air (kg s^{-1})
$\dot{m}_{air}$	mass rate of dry air (kg s^{-1})
$\eta_{ex,HP}$	exergy efficiency of heat pump
$\dot{E}x_{heat}$	exergy of heat energy given to the cooling fluid at condenser (kW)
$\dot{E}x_{in\ cond}$	rate of total exergy inlets to the condenser (kW)
$\dot{E}x_{out\ cond}$	rate of total exergy outlets from the condenser (kW)
$\dot{E}x_{dest\ HP}$	rate of total exergy destructions at the heat pump (kW)
$\dot{E}x_{in\ HP}$	rate of total exergy inlets to the heat pump (kW)
$\dot{E}x_{out\ HP}$	rate of total exergy outlets from the heat pump (kW)

when compared with conventional or traditional heating systems. Heat pump systems do not produce exhaust gases while heating any space and use less energy than other systems. In addition, heat pumps are capable to use the abundant natural resources such as air source, geothermal source, waste heat and the heat of the soil. Heat pumps are widely used not only for air conditioning and heating applications, but also cooling, producing hot water and preheating feed water in various types of facilities including office buildings, public buildings, computer centers, restaurants. In addition to plants, heat pump applications have a great variation in type of drive energy, size of systems, operating conditions, variable heat sources and sinks, and application type. 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 which have specific properties in general and therefore they are unique setups. In short, they provide with high levels of comfort, make significant reductions in electrical energy consuming and they are friendly systems for the nature [4].

Although a simple heat pump system consists of four main components, which are compressor, two heat exchangers (condenser and evaporator) and expansion valve, many auxiliary components may be used on heat pumps such as valves, thermostats, some measurement tools, pumps, fans, or extra heaters. The main structure and the type of new heat pumps have changed very much due to the improving technology and changing thermal demands all over the world. The properties of the components used on heat pumps are effective on the performance and on the thermodynamic behavior of heat pumps. In addition, thermal characteristics and the types of the 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 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 decreases depending on a decrease in the air temperature during the heating seasons and increase in the air temperature 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. Heat Pump systems are available in array of types and combinations that can suit almost any application. 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 either to absorb or reject the heat in each of these locations. For both of the heat exchangers, the heat transfer appliance can be either liquid (water, or often a glycol mixture) or air; sometimes it is a combination of these two. While describing the type of heat pump, generally the heat source is 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.

Because of the fact that utilization of heat pump has been spread all over the world as a result of the improvements and developments on it, the structure of heat pumps, types and the sizes of the components used on heat pump systems have changed very much and in the light of these developments, modern and more