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PERFORMANCE ANALYSIS OF WATER HEATERS WITH RENEWABLE HEAT SOURCE

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Abstract: A heat pump system used for domestic hot water supply was analyzed regarding to its performances in function of its heat source (i.e. outdoor air) temperature variation. Also, as the air-source temperature directly influences the evaporation process, the obtained efficiency results (i.e. COP_{en} and COP_{ex}) are plotted versus evaporating temperature. This study aims performance analysis in terms of efficiency determination for an air-source heat pump system which operates in different conditions (i.e. outdoor air temperature variation in the range $(-5 \div 35)°C$, chosen according to product specifications of a water heater with defrosting function). Thus, the Engineering Equation Solver (EES) software is used in heat pump system's analysis which offers useful information on vapor compression refrigeration cycles
Keywords: heat pump system, renewable energy heat source, energy and exergy, COP

1. INTRODUCTION

Like refrigeration systems, heat pumps have the same basic components (compressor, condenser, expansion valve and evaporator, connected by pipes in which a working fluid operates). More details about the working principle as well as the vapor compression thermodynamic cycle performed by heat pumps are given elsewhere [1]. The difference between these two devices is that for the first one, the interest is its cooling capacity (developed by the system's evaporator), while for the second one, of interest is its heating capacity (developed by the system's condenser).

Lately, were designed heat pumps for domestic hot water supply which operates with renewable heat sources as: outdoor air, ground or ground water [2-4]. To highlight their most important advantage, in Figure 1 is presented the energy balance of a water heater working with electric resistance versus heat pump system [2]. So, while the first system uses 100% electric supply to heat the water, the heat pump systems can take up to 70% of needed energy form renewable heat sources. The heat pump only uses electric energy to run the compressor during the thermodynamic cycle and to act the fan which captures the outdoor air [2].

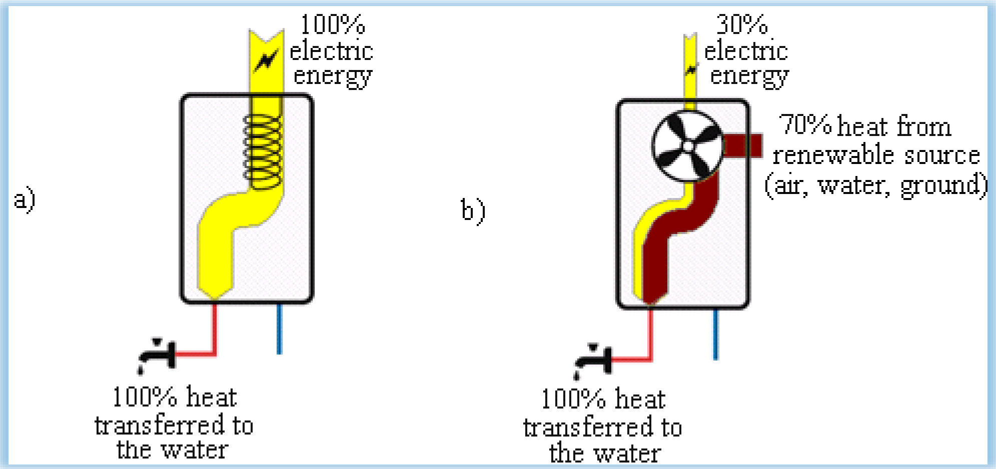

Figure 1. Energy balance comparison between electric resistance water heater (a) and heat pump systems (b) [2].

Also, while ground water heat sources exhibit small temperature variations during the year, and ground heat sources exhibit almost no temperature variations, the outdoor air heat source varies much during the year. Consequently these variations influence the system efficiency [3].

This study aims performance analysis in terms of efficiency determination for an air-source heat pump system which operates in different conditions (i.e. outdoor air temperature variation in the range $(-5 \div 35)°C$, chosen according to product specifications of a water heater with defrosting function [2]). Thus, the Engineering Equation Solver (EES) software is used in heat pump system's analysis which offers useful information on vapor compression refrigeration cycles [3, 5, 6].

2. EVALUATION CRITERIA OF HEAT PUMP SYSTEMS EFFICIENCY

In order to determine the efficiency of the heat pump system, the operating conditions of the thermodynamic cycle must be specified; the analyzed operating cycle is presented in Figure 2 by state points 11'233'4. This includes evaporating and condensing temperatures, T_E and T_C, respectively. In case of air-source heat pump systems, their values are given by the considered outdoor air temperature, T_A (at the entry into evaporator), and required hot water temperature, T_H (at the outlet of the condenser), respectively, considering some temperature differences. According to [3], these temperature differences are: in the evaporator (temperature difference between air temperature at the entry into evaporator and evaporating temperature) $\Delta T_E = 10°C$, and in the condenser (temperature difference between hot water temperature at the condenser outlet and condensing temperature) $\Delta T_C = 5 \div 10°C$.

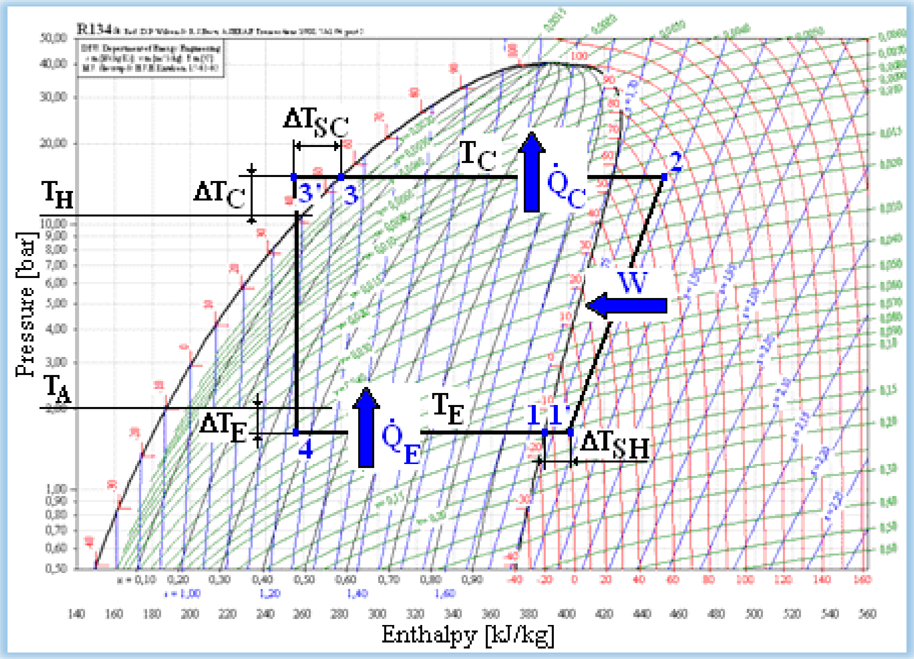

Figure 2. Real operating cycle of a heat pump system represented in lg(p)-h diagram (the working fluid is R134a).

So, the characteristic temperatures of the operating cycle can be determined as [3]:

$$T_C = T_H + \Delta T_C \tag{1}$$

$$T_E = T_A - \Delta T_E \tag{2}$$

As mention above, according to product catalogue of a heat pump system with a defrosting function, working conditions require a temperature range for outdoor air source of $(-5 \div 35)°C$, while the maximum reached hot water temperature is 55°C [2].

Also, the real operating cycle take place with a certain degree of superheating in evaporator (1-1' process in Figure 2) and of subcooling in condenser (3-3' process in Figure 2). These degrees are considered to be of $\Delta T_{SH} = \Delta T_{SC} = 5°C$ [3].

In this study the air-source heat pump system efficiency analysis is carried out using Engineering Equation Solver software [6]. Taking into account all the above, considered inputs are: R134a working fluid with a mass flow of $\dot{m} = 1 kg \cdot s^{-1}$; $\eta_{is} = 0.8$ (compressor isentropic efficiency); $T_A = (-5 \div 35)°C$, with a step of 5°C; $\Delta T_E = 10°C$; $T_H = 45°C$; $\Delta T_C = 10°C$; $\Delta T_{SC} = 5°C$; $\Delta T_{SH} = 5°C$. Also, condensing temperature, determined with equation 1 is $T_C = 55°C$ and is maintained constant during analysis, while evaporating temperature, determined with equation 2 varies in the range $T_E = (-15 \div 25)°C$ with a step of 5°C.

The most common measure of heat pump systems efficiency is the coefficient of performance (COP), which may be defined on energy and exergy bases as COP_{en} and COP_{ex}, respectively, as follows [3]:

$$COP_{en} = \frac{\dot{Q}_C}{W} \; [-] \tag{3}$$

where $\dot{Q}_C$ [kW] is the overall system heating capacity and W [kW] is the overall compression work (see Figure 2).

$$COP_{ex} = \frac{COP_{en}}{COP_{Carnot}} \; [-] \tag{4}$$

where $COP_{Carnot} = T_H / (T_H - T_A)$ is the system efficiency considering an ideal working cycle (reversible Carnot cycle) which operates between the same temperature levels as the considered heat pump system (i.e. hot and cold heat sources temperatures, T_H and T_A, respectively). To calculate COP_{Carnot}, the temperature values must be taken in Kelvin [1].

3. RESULTS AND ANALYSIS

Figures 3 and 4 show the results of heat transfer rate in condenser (system heating capacity), $\dot{Q}_C$ [kW]; heat transfer rate in evaporator (system cooling capacity), $\dot{Q}_E$ [kW] and corresponding compressor work, W [kW].

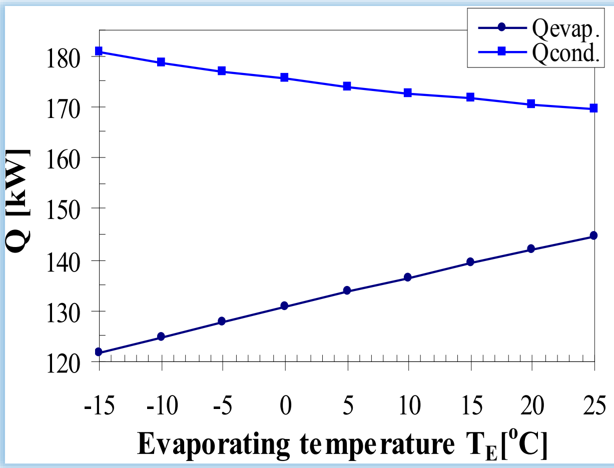

Figure 3. Heat transfer rates in evaporator and in condenser versus evaporating temperature. T_C=55°C.

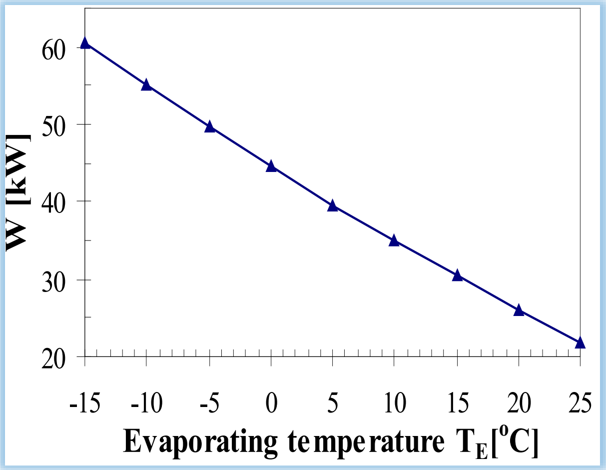

Figure 4. Compressor work versus evaporating temperature. T_C=55°C.

As observed, the heating capacity of the heat pump system varies little in the evaporating temperature analyzed range (the upper curve in Figure 3). This is because we have considered constant condensing temperature during analysis (T_C=55°C). Also, the cooling capacity increase as the evaporating temperature increases, with a maximum value of about 23 kW obtained between range limits. Otherwise, as expected, the compressor work decrease with increasing evaporating temperature (see Figure 4). Up to the right side of evaporating temperature range, the compressor work diminishes by 3 times.

The coefficients of performance COP_{en} and COP_{ex} are plotted versus evaporating temperature in Figures 5 and 6, respectively.

The COP_{en} coefficient was determined with equation (3) on energy bases (First Law of Thermodynamics), while the COP_{ex} coefficient was determined with equation (4) on exergy bases (Second Law of Thermodynamics).

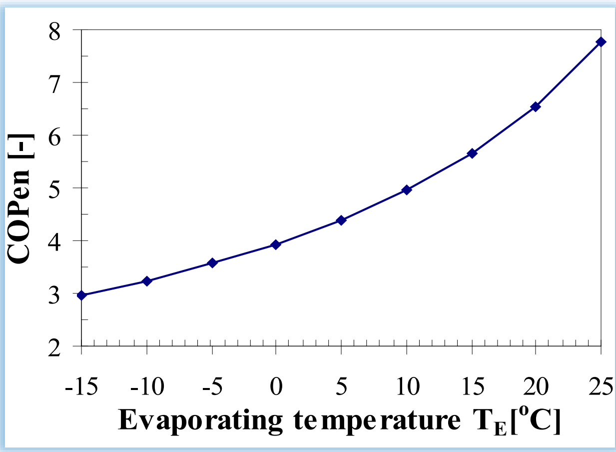

Figure 5. Variation of COP_{en} with evaporating temperature. T_C=55°C.

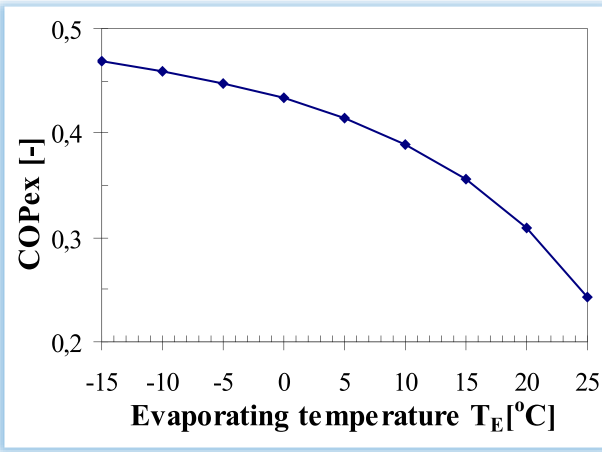

Figure 6. Variation of COP_{ex} with evaporating temperature. T_C=55°C.

Through the evaporating temperature range, the COP_{en} coefficient of the analyzed system increases constantly, having a minimum value of 3 at evaporating temperature of -15°C (Figure 5). But even at the lowest evaporating temperature the energetic efficiency is supraunitary, meaning that the system distribute energy of three times more than it consumes. At evaporating temperature of 25°C, the COP_{en} coefficient has a value of 7.8, which means an increase of about 2.5 times along the evaporating temperature range. As it is obtained as the ratio between COP_{en} and the reversible Carnot cycle efficiency, the COP_{ex} coefficient has subunitary values, which decreases between the evaporating temperature range limits by 2 times (from 0.47 at -15°C to 0.24 at 25°C), Figure 6.

4. CONCLUSIONS

Regarding air-source heat pumps, the most important parameter influencing system's performance is outdoor air temperature as it varies in a wide range during the year. The analysis was done with the use of Engineering Equation Solver (EES) software to establish how this parameter influences the heating capacity, compressor work and efficiency of the system.

It was found that in the range of values of $(-5 \div 35)$°C for the outdoor air temperature, the system's efficiency, namely the coefficient of performance COP_{en} increase up to about 2.5 times, while COP_{ex} decrease up to 2 times.

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