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Thermal Performance Evaluation of Air Cooled air Conditioning Unit Under Iraq Climate

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ABSTRACT

Small air conditioning units are usually used for small and medium scale residential buildings. Therefore, more energy efficiency and lower cost are needed along with reliable control for the air conditioning units. An experimental investigation has been carried out to study the performance of a direct expansion air conditioning unit under abnormal surrounding ambient conditions. To facilitate variation of refrigerant flow rate according to the evaporator load, a suitable thermostatic expansion valve and liquid refrigerant reserve was used. The influence of evaporator airflow and its temperature on the air conditioning unit performance and compressor power consumption has been investigated. The performance of air conditioning unit is simulated using the TRANSYS Simulation Program. The model is validated by real operating data from the system. It has been found that a 14.28 % reduction in compressor power consumption is achieved by decreasing the condenser inlet air temperature from 50 to 35 ºC. The cooling capacity of the evaporator was increased by 32.2 % with decreasing the condenser inlet air temperature from 50 to 35 ºC, Also it was increase by 7.56 % with increasing the evaporator entering air volume flow rate from 300 to 600 m^3/hr. It can be concluded that the COP increases by 19.84 % with increasing the condenser inlet air temperature from 50 to 35 ºC. The modeled results of the air conditioner's COP show agreed well with the corresponding measured data, the uncertainty was within ±11.9 %.

Introduction

The increasing consumption of energy in buildings on heating, ventilating and air-conditioning (HVAC) systems has initiated a great deal of research aiming at energy savings. With the consolidation of the demand for human comfort, HVAC systems have become an unavoidable asset, accounting for almost 50% energy consumed in building and around 10-20% of total energy consumption in developed countries. The direct expansion (DX) air conditioning plant is one of the main HVAC systems for different types of buildings. Its operation has a significant effect to the overall building energy consumption. DX air conditioning plants are simpler in configuration and more cost-effective to maintain than central cooling ones using chillers and cooling towers. Therefore, these systems have a wide application in small to medium size buildings. The performance of DX systems can be improved by determining the optimal decision variables of the system to address the issues of energy savings and occupant comfort [1,2].

The performance of air conditioner depends on heat transfer between the coils and the airflow. In this regard, air-cooled condensers need a high airflow rate for improved performance, and thus sometimes results in noise problem. So in general, the coefficient of performance can be improved by lowering the compressor power consumption, increasing the cooling and heat rejection capacity, decreasing the refrigerant pressure loss, or reducing the pressure difference between the condenser and evaporator. Reducing the pressure difference between the condenser and evaporator is the fruitful one in comparison with those mentioned above. While the evaporating temperature is kept constant, lowering the condensing temperature results in the reduction of pressure difference.

Elsayed and Hariri investigated experimentally the performance of a direct expansion air conditioning (A/C) unit having a variable speed condenser fan. The modulation of heat rejection airflow has been controlled with the outdoor air temperature. The influence of condenser airflow and its temperature on the A/C unit performance and compressor power consumption has been investigated and presented at different evaporator cooling load. It has been found that a 10 % reduction in compressor power consumption is achieved by increasing the condenser air flow by about 50%.

Recently, **Mahlia and Saidur [4]** reviewed requirements and specifications of various international test standards for testing and rating of room air conditioners and refrigerators sacking for efficiency improvement of these appliances. Also, **Jiang et al [5]** evaluated the influence of condensing heat recovery on the dynamic behavior and performance of air conditioners. They showed that the condensing heat recovery has a negative effect on the cooling capacity at the start of the heat recovery process, while the average COP of the system is improved.

Wang et al [6], reported that if the on-coil temperature of a condensing unit were raised by 1^{o}C, the coefficient of performance (COP) of the air conditioner would drop by around 3%. In addition, if this temperature remained above 45^{o}C for an extended period, the air conditioner would trip because of the excessive condenser working pressure.

Hwang et al [7] carried out a 7.4 kW residential split heat pump system utilizing an evaporative-cooled condenser. The test results showed that COP was increased by 11.1–21.6% as compared to the air-cooled condenser. However, the size of

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Hwangs system was too large, heavy and complicated for residential application.

A simple prototype of water-cooled air conditioner of split type developed by **Hu and Huang [8]** by using cellulose pad as the filling material of the cooling tower. The experimental results showed the coefficient of performance COP reaches 3.45 at wet bulb temperature 27°C, dry bulb temperature is 35°C and that is higher than the standard value 2.96 of those conventional residential air conditioners.

Experimental apparatus and procedure

A computerized laboratory air conditioner has a model of ET600 and manufactured by G.U.N.T in Germany. It was modulated in order to be used for conducting experiments as shown in figures (2). It combines the compressor, DX condenser, throttling valve, and DX evaporator. The refrigeration cycle used R134a as a refrigerant; the apparatus contains a simple duct work flow system to simulate an actual air conditioner. The system is equipped with a steam humidifier for regulating the moisture content of the air flow. An air flow schematic diagram of the ET600 system is presented in figure (3).

There are three separate inter connected systems in this apparatus: air flow loop, refrigeration cycle and steam humidifier. The refrigeration cycle is completely separated from other except where it cools air in the evaporator. The air conditioning system contains three stages preheater and reheater in the path of entering air to the evaporator, and another heater in the front of condenser. Each heater was connected with variable capacity transformers to control the heater power, consequently to control the air entering to the condenser and evaporator to the desired temperatures. Air is passed through the duct work flow system by a three speeds centrifugal fan mounted at the duct intake. The fan pulls air in through an orifice which is equipped with a horizontal manometer; the air mass flow rate was modulated by varying the evaporator fan speed.

All measuring sensors were connected to a LED digital display, enabling Temperatures and humidity to be taking during experiments. The liquid refrigerant mass flow rate was measured by a calibrated flow meter with a maximum uncertainty of ±0.5 kg/h. A digital watt meter with ±1% reading uncertainty was provided to measure the compressor consumption. The apparatus is equipped by thermocouples type T with a maximum uncertainty of ±0.2% and relative humidity sensors with a maximum uncertainty of ± 1%, were installed at the inlet and outlet of the evaporate and condenser. Also, a thermo couples type T was installed along the tube length of the evaporator and condenser to determine the condensation and evaporation temperatures.

The apparatus has a nominal cooling capacity of 1.2 kW, rated under the operating conditions of entering condenser air temperature, $T_{ca,,i}$ at 35°C, entering/leaving cooled air temperatures at 25°C/12°C and air flow rate at 360 m^3/h. The rated power consumption is 0.5 kW. The rated COP is, therefore, about 2.4. The air-cooled condenser contains condenser fan to deliver a airflow rate of 540 m^3/h.

All tests were performed in an identical manner and at steady state. The experiments were repeated by varying the condenser inlet air temperature as: 35, 40, 45, and 50 °C, and by varying the evaporator air flow rate as: 300, 390, 480, and 600 m^3/hr. It is worth monitoring that the room temperature was maintained around 25℃, during the experiments.

The refrigeration cycle shown in figure (1) is changed from the cycle 1-2-3-4-1 to 1'-2'-3'-4'-1'.With the decrease of the condensing pressure, the work of the compressor will decrease. However, the cooling capacity increases, so the COP of the system will increase.

The aim of this paper is to adapt a simplified model for analyzing the thermal performance of air conditioner under Iraqi climate. The analysis of energy and mass balance will define the mathematical models for both air cooled air conditioner and water mist, which will compare with the experimental measurements.

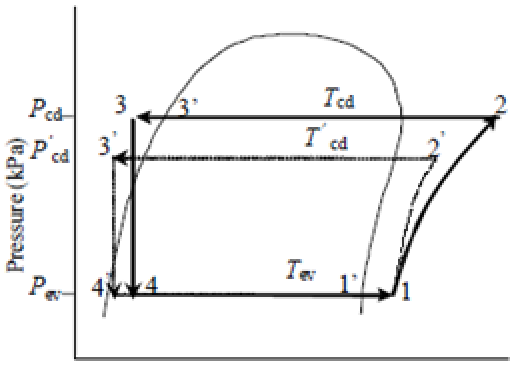

Fig 1. Vapour compression refrig. Cycle

Fig 2. Air-conditioning system, ET600

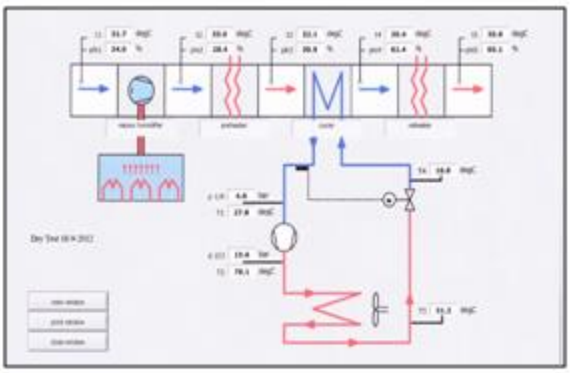

Fig 3. A schematic diagram of ET600

Mathematical Modeling

The aim of this paper is to adapt a simplified model for analyzing the thermal performance of air cooled air conditioner under Iraq climate. The performance of the air conditioning unit is simulated using the TRANSYS Simulation Program**[9]**, which will compare with the experimental measurements. The measured operating data for the air-cooled air conditioner included the power of compressor, W_{comp}; the power of refrigeration cycle, which equal to the power of compressor plus the power of fan, T_{ev} and condensing temperature, T_{cd} of refrigeration cycle. The cooling capacity of the air conditioner, Q_e is:

$Q_e = m_r \cdot (h_{r,1} - h_{r,4})$ (1)

Where m_a is the cooled air mass flow rate, where: $h_{ea,i}$, $h_{ea,o}$ are enthalpies of the air at evaporator inlet and outlet, respectively (kJ/kg).

Heat rejection, Q_c was calculated by Eq. (2).

$Q_c = m_r \cdot (h_{r,2} - h_{r,3})$ (2)

and

$Q_c = Q_e + W_{comp}$ (3)

The air conditioner COP is expressed as cooling capacity, Q_e over power consumption W_{rp}, as follow:

$COP = Q_e / W_{comp}$ (4)

For any given cooling capacity, Q_e, compressor power, W_{comp} and heat rejection, Q_c will vary according to the condensing temperature, T_{cd}. The performance of the entire air conditioning system is simulated by the air conditioner model using the TRANSYS Simulation Program **[9]**. All the measured parameters taken from experimental runs, such as: condenser and evaporator air inlet dry and wet bulb temperatures, condenser and evaporator air mass rates, and power consumption were fed the program as input data. All computed parameters taken from the output from the computer which are: The temperature of condenser air entering, cooling capacity, and COP.

Results and Discussions

Effect of condenser inlet temperature

The condenser inlet air temperature affects the performance of the refrigeration cycle of air conditioner. As, mentioned, the increase of condensing pressure of the cycle accompanying the increase of condensing temperature with increasing the condenser inlet air temperature due to the proportion relation between them.

Figure (4) shows the effect of condenser inlet air temperature on the refrigeration cooling capacity of the cycle. The cooling capacity decreases with increasing condenser inlet air temperature due to increase of refrigeration effect and refrigerant mass flow rate, an increase of compression ratio causes a decrease in volumetric efficiency and consequently lower values of refrigerant mass flow rate. The reduction in cooling capacity is about 32.2%, as the condenser inlet air temperature decreased from 50 to 35 ºC.

Figure (5) shows the effect of condenser inlet air temperature on the consumption power of compressor. It is seen that the consumption power was increased with increasing the condensing temperature due to increasing the condensing pressure, which will definitely increase the enthalpy difference. An increase of compression ratio causes an decrease in volumetric efficiency and consequently lower values of refrigerant mass flow rate, which don't overcomes the increasing of the enthalpy difference. The power consumption is decreased by 14.28 %, as the condenser inlet air temperature increased from 50 to 35 ºC.

In case of studying the effect of condenser inlet air temperature on COP. It is found that the COP increases by 19.84 %, as the condenser inlet air temperature decreased from 50 to 35 ºC as shown in Fig (6).

Effect of evaporator air flow rate

The evaporator air flow rate affects the thermal performance of the refrigeration cycle of air conditioner. The air flow rate was regulated by varying the speed of evaporator fan. As, mentioned, the increase of evaporating pressure of the cycle accompanying the increase of evaporating temperature with increasing the evaporator air flow rate due to the proportion relation between them.

Figure (7) shows the effect of evaporator air flow rate on the refrigeration cooling capacity of the cycle. The cooling capacity increases with increasing condenser air flow rate due the increase of evaporating temperature which causes to increase both of refrigeration effect and the refrigerant mass flow rate.

The cooling capacity is increased by 7.56 %, as the evaporator air flow rate increased from 300 to 600 m^3/hr. It is clear that the consumption power was increased by 8.7 % with increasing the evaporator air flow rate from 300 to 600 m^3/hr due to the cubic relation between the fan power and air flow rate (fan laws) as shown in figure (8).

In case of studying the effect of evaporator air flow rate on the COP. It is found that the coefficient of performance decreases by 9.69 % with increasing the evaporator air flow rate from 300 to 600m^3/hr as shown in Fig (9).

The validity of the performance of the entire air conditioning system model, which is integrated the air conditioner model and water mist model was checked by comparing the modeled results with the operating data of the air conditioner. The modeled results of the air conditioner's COP show agreed well with the corresponding measured data, the uncertainty was within ±11.9 %.

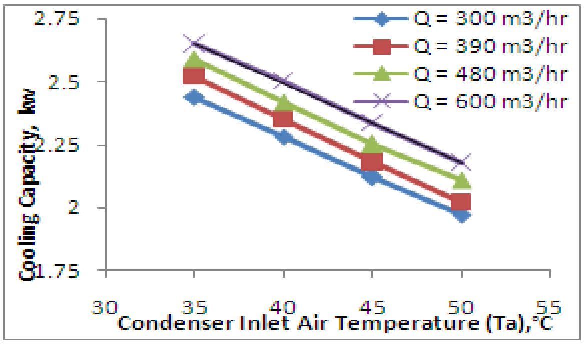

Fig 4. Influence of the condenser inlet air temperature on cooling capacity for different evaporator air flow rate

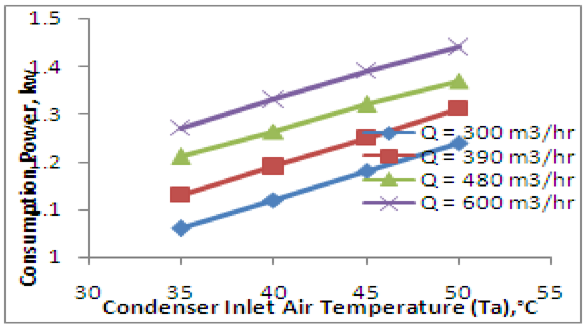

Fig 5. Influence of the condenser inlet air temperature on power consumption for different evaporator air flow rate

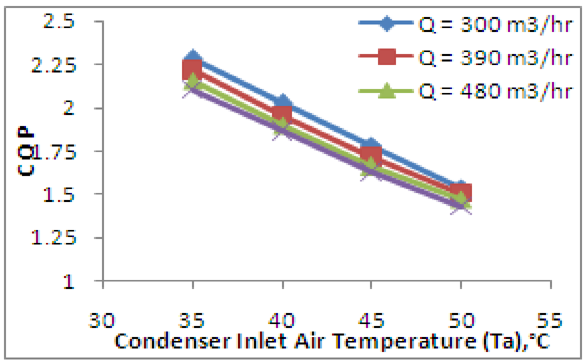

Fig 6. Influence of the condenser inlet air temperature on COP for different evaporator air flow rate

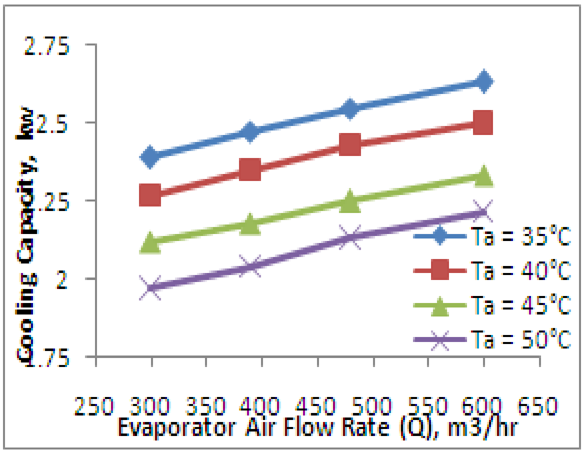

Fig 7. Influence of the evaporator air flow rate on cooling capacity for different condenser inlet air temperature

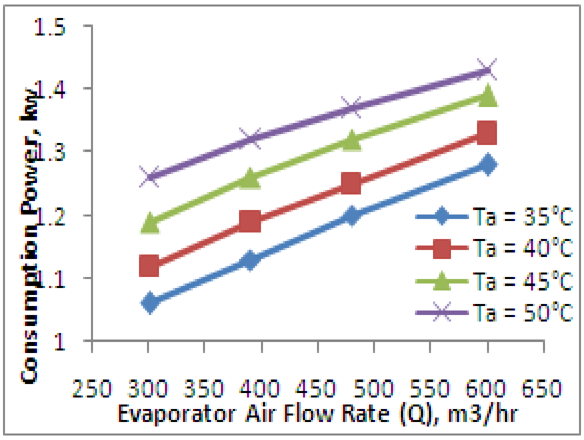

Fig 8. Influence of the evaporator air flow rate on power consumption for different condenser inlet air temperature

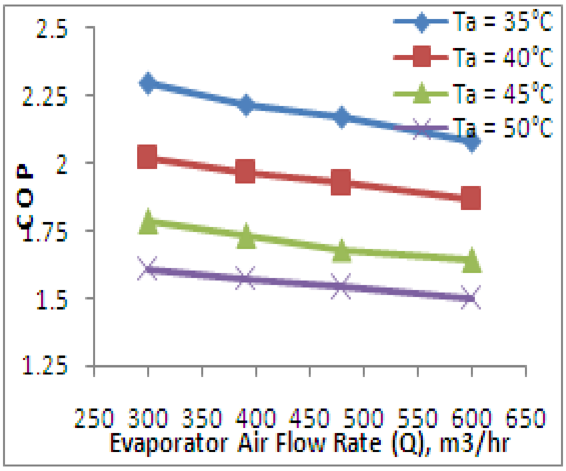

Fig 9. Influence of the evaporator air flow rate on COP for different condenser inlet air temperature

Conclusions

From the above findings, it can be concluded that:

- The consumption power of the compressor was decreased by 14.28 % and the cooling capacity was increased by 32.2 %, as the condenser inlet air temperature decreased from 50 to 35 ºC.

- The cooling capacity of the evaporator was increased by 7.56 % when raising the evaporator entering air volume flow rate from 300 to 600 m^3/hr, while the consumption power was increased by about 8.7 %.

- The coefficient of performance of the air conditioner was increased by 19.84 %, when raising the evaporator entering air volume flow rate from 300 to 600 m^3/hr.

Nomenclature

Symbol	Definitions	Units
h	enthalpy	kJ/kg
m	mass flow rate	kg/s
Q_e	cooling capacity	kw
Q_c	heat rejection	kw
W_{comp}	compressor work	kw

Subscripts

cd	condensing
ev	evaporation
r	refrigerant

Abbreviations

COP coefficient of performance [-]

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