# Management of Condenser Fan Speed and its Influence on the Split Air Conditioner Performance

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**Abstract:** Energy saving is the challenge of decreasing the quantity of energy consumption needed. This can be done by employing reliable and smart control system. In this article, an experimental study has been carried out to investigate the performance of a split air conditioning unit having a variable speed condenser fan. The rate of heat rejection airflow has been controlled according to the outdoor air temperature via a Proportional Integral Differential (PID) controller. The control algorithm allows increasing the condenser fan speed with the increase of outdoor air temperature and vice verse. The maximum rate of air flow of the fan is 0.43 $m^3/s$ at 42ºC outdoor air temperature and the minimum flow is 0.28$m^3/s$. To facilitate variation of refrigerant flow rate according to the evaporator load, the traditional capillary tube was replaced with a suitable thermostatic expansion valve and liquid refrigerant reserve. The influence of condenser airflow modulation and its temperature on the air conditioner performance and also on the compressor power consumption has been investigated and presented at different evaporator loads. It has been found that a 10 % reduction in compressor power is achieved by increasing the condenser air flow by about 50%.

**Keywords:** Split air conditioners, A/C unit performance, Variable speed condenser fan.

## 1. INTRODUCTION

The energy efficiency is aimed to decrease the consumption of energy used. It could be achieved through efficient energy use or by improving the performance of refrigeration cycle, e.g. [1-4]. Air conditioning units are usually used for small and medium scale residential buildings. The amount of national energy consumed by air conditioners is about 67.34% of the total residential energy consumption [5]. Therefore, an improvement in the refrigeration cycle performance becomes essential. This improvement in the cycle performance can be accomplished by lowering the compressor power, increasing of heat rejection ability from the condenser or reducing the difference between condenser and evaporator pressures.

Hu and Huang [6] offered a high efficiency split residential water-cooled air conditioner that utilizes cellulose pads as a filling material in the cooling tower. They showed that the usage of water cooled condenser results in decreasing the compressor power consumption from 1.189 to 1.02 kW and the cycle COP has been improved from 2.96 to 3.45. Potential energy saving for using water cooled air conditioner in residential building has been illustrated by Chen *et al*. [7]. A split air conditioner water cooled condenser type was set up for experimental study at different indoor and outdoor conditions. The overall energy saving has been estimated to be around 8.7% of the total electricity consumption. Mahlia and Saidur [8] reviewed requirements and specifications of various international test standards for testing and rating the room air conditioners and refrigerators sacking for efficiency improvement of these appliances. Also, Jiang *et al*. [9] 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.

Yu and Chan [10] showed how the COP of the air-cooled chillers can be improved by modulating heat rejection airflow by using variable speed condenser fans. They introduced an algorithm that makes use of a set point of condensing temperature to determine the speed of condenser fans staged to provide the airflow required for any given heat rejection. Also, for achieving maximum COP under variable speed condenser fans, the set point of condensing temperature should be adjusted based on the chiller load together with the outdoor temperature. Mohammed *et al*. [11] experimentally and analytically investigated the improvement of performance of a split A/C system by using a smart control system integrated with PID algorithm. The control system was employed to control the speed of condenser fan. The DC motor of condenser fan was adjusted over two intervals of ambient temperature, which are 35-40°C and 40-57°C. The authors found that the use of PID controller improves the performance of the A/C system,

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E-ISSN: 2409-5818/19 

especially, in the range of 35-40°C of ambient temperature. Also, the power consumed by the compressor had been reduced by 5.96–34.09% in the range of 37-57°C ambient air temperature. Kang *et al*. [12] presented a control algorithm model for variable refrigerant flow operation in a cooling system working with variable optimal set-points. The model has been designed to predict the energy consumption, where the most energy-effective set-points can be determined to optimally operate the cooling system. They found that the control algorithm model markedly saved the cooling energy consumption by 28.44% during the 62 days.

The main objective of this study is to investigate the effect of condenser heat rejection modulation, via a variable speed fan, on the energy consumption and also, on the performance of a residential air conditioner. The speed of condenser fan was simultaneously controlled with the outdoor air temperature. The characteristics of refrigeration cycle are presented at different indoor and outdoor temperatures at the steady state operation condition.

## 2. EXPERIMENTAL APPARATUS AND PROCEDURE

A split air conditioner having 2.64 kW nominal capacity using R-22 was employed to exam the modulation of condenser heat rejection and its effect on the conditioner performance. The conditioner contains the basic components of vapor compression system: a compressor, a condenser, capillary tube, an evaporator, filter/dryer and fans. The indoor unit includes a DX evaporator with copper tubes and aluminum fins, a fan and a capillary tube. The outdoor unit includes a constant speed rotary compressor and an aluminum finned-plate condenser that is provided with a constant speed propeller fan. The cooling output has ON/OFF control in accordance with the indoor set point temperature.

The normal method of adjusting the refrigerant mass flow in the evaporator is to add an expansion valve and an accumulator to the system. Therefore, a thermostatic expansion valve (with 0-1 orifice) and 1 kg liquid refrigerant accumulator have been installed in the refrigeration cycle. The condenser fan was employed to extract the room air through a foam duct and discharge it outside the room as shown in Figure **1**. Electric heaters were installed in the path of entering air to evaporator and condenser. Each heater was connected with a variable capacity transformer to control the heater power.

The refrigeration cycle of the conditioner was provided with controlling and measuring devices at the key locations of cycle. A schematic diagram of the experimental apparatus is shown in Figure **2**.

The temperature was measured via T-type thermocouple with a maximum uncertainty of ± 0.2ºC. Thermocouples were placed at the inlet and outlet of the evaporator and condenser. Also, thermocouples were installed along the tube length of the evaporator and condenser to determine the condensation and evaporation temperatures. The thermocouple junctions were soldered at the outer surface of the tubes and the thermocouple wires were connected to a digital thermometer. The condition of air at the inlet and outlet of each of evaporator and condenser was measured by means of a digital humidity/temperature meter with 1% accuracy of relative humidity and ±0.1 accuracy of dry bulb temperature. The liquid refrigerant mass flow rate was measured by a calibrated flowmeter with a maximum uncertainty of ±0.5 kg/hr. A digital wattmeter

(a) Condensing unit (b) Evaporating unit

**Figure 1:** Photographic picture of the air conditioning unit.

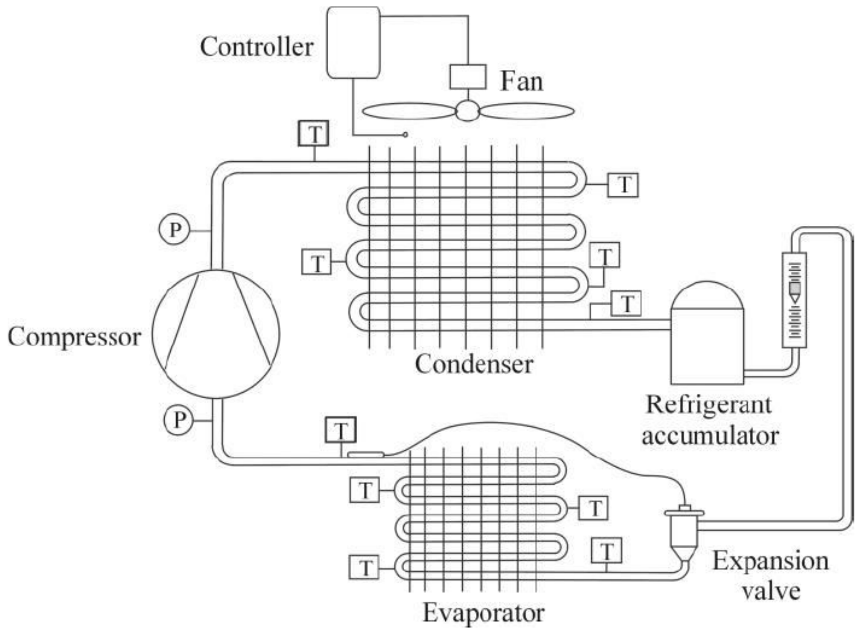


**Figure 2:** Schematic view of the experimental apparatus.

with ±1% reading uncertainty was provided to measure the compressor power consumption.

A Proportional Integral Derivative (PID) controller was used to control the speed of condenser fan. The controller had been connected with a temperature sensor, thermistor (LM35), which was positioned inside the foam duct at the front of condenser. When the condenser inlet air temperature is increased above the desired set point, the condenser fan speed is increased and vice verse. The velocity of air at the inlet condenser coil was measured via a digital vane anemometer with 0.1 m/s accuracy, where the air velocity inside the condenser duct ranged from 1.25 to 1.9 m/s. It is worth mentioning that the room temperature was maintained at 24-26 ºC during the experiments. All test runs were performed in an identical manner and at the steady state condition.

## 3. DATA REDUCTION

As mentioned, the air velocity (m/s) inside the condenser duct was measured via a vane anemometer and the rate of air flow ($m^3$/s) is calculated by multiplying the duct cross section into the average air velocity. The evaporator cooling capacity, $Q_{ev}$, can be calculated as:

$$Q_{ev} = m_{ref} (h_{out} - h_{in}) \tag{1}$$

Where: $h_{out}$, $h_{in}$ are enthalpies of the refrigerant at evaporator outlet and inlet, respectively (kJ/kg). The common approach in determining the refrigeration cycle performance is to use the coefficient of performance, COP, depending on the compressor power consumption as:

$$COP = Q_{ev} / W_{comp} \tag{2}$$

## 4. RESULTS AND DISCUSSION

The performance of the refrigeration cycle is a result of balance between the four essential cycle components. The affecting parameters that influence the conditioner performance have been considered through the following sections. Also, the modulation of condenser heat rejection airflow and its effect on the conditioner performance has been presented.

### 4.1. Effect of Evaporator Entering Air Temperature

The refrigeration load of the evaporator may vary due to several reasons, such as the variation of ambient temperature. The influence of entering air temperature (return air temperature) on the evaporating temperature, $T_{ev}$, and consequently on the evaporator cooling capacity, $Q_{ev}$, is presented in Figure **3**. It is observed in this figure that higher cooling capacity is achieved at 26ºC which is the design operation condition recommended by manufacturer. As the entering air temperature increases the evaporating temperature increases and the cooling capacity decreases.

The reduction in $Q_{ev}$ is about 25%, when the inlet air temperature is increased from 26 to 35ºC. This

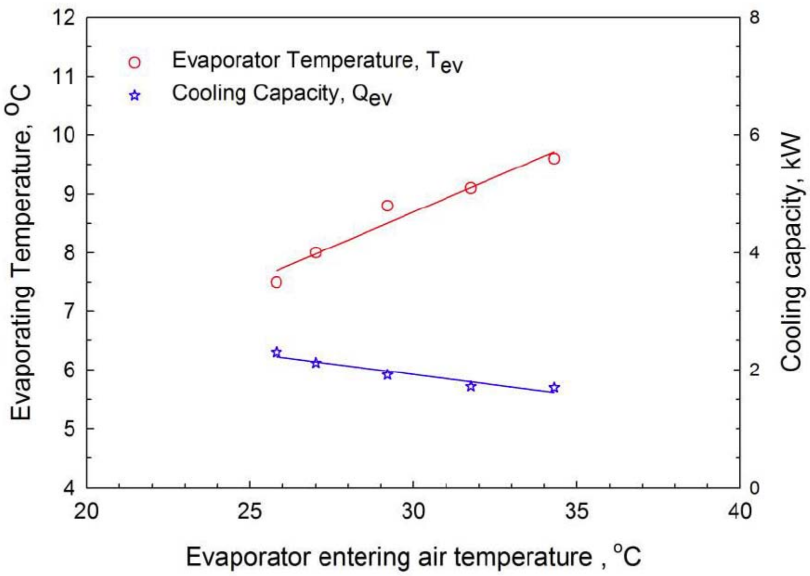


**Figure 3:** Variation of evaporator temperature and evaporator cooling capacity with entering air temperature.

reduction in $Q_{ev}$ is due to the evaporator starving by reduces the heat transfer coefficient in evaporator, since there is no sufficient refrigerant to accommodate the heat load. Here, it should be mentioned that the degree of superheating has been changed from 5 to 9 ºC and the corresponding mass flow rate of the refrigerant varied from 38 to 47.9 kg/hr. Also, the degree of subcooling varied from 2 to 3ºC.

Figure **4** shows that as the evaporator entering the air temperature increases the compressor power increases, which cause a reduction in the coefficient of performance of the cycle. The increase of power consumption is about 12%, while the reduction in COP is about 35%.

### 4.2. Effect of Condenser Inlet Air Temperature at Constant Condenser Fan Speed

The effect of condenser inlet air temperature on the cycle performance is shown in Figure **5**. The temperature of the air entering the condenser was varied by heating the supply air to the desired temperature. During these experiments, the ambient temperature was kept constant at 26 ºC and the speed of condenser fan was kept constant at 0.28 $m^3$/s of air.

Figure **5** shows the variation of compressor power and COP of the cycle with the condensation temperature at different condenser inlet air temperatures. It is observed from this figure that 17% increase in the condensing temperature leads to an

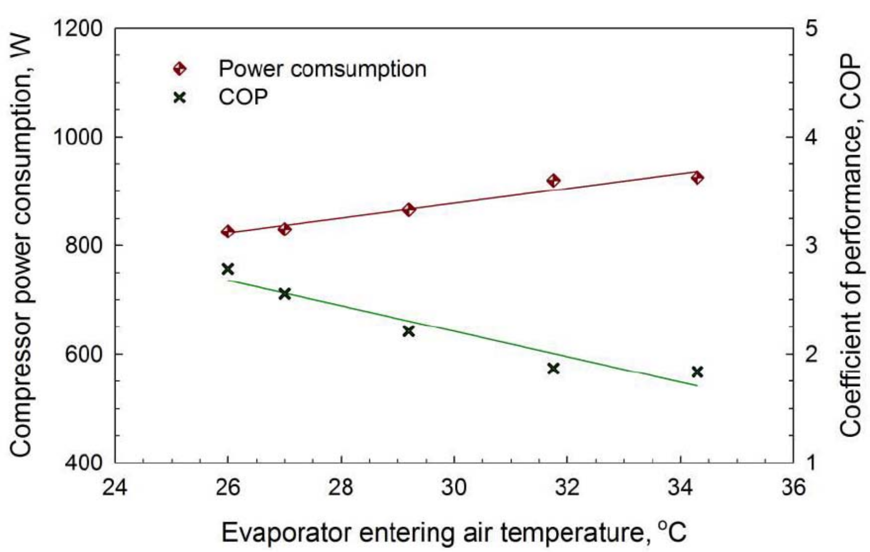


**Figure 4:** Effect of evaporator entering air temperature on the compressor power and cycle performance.

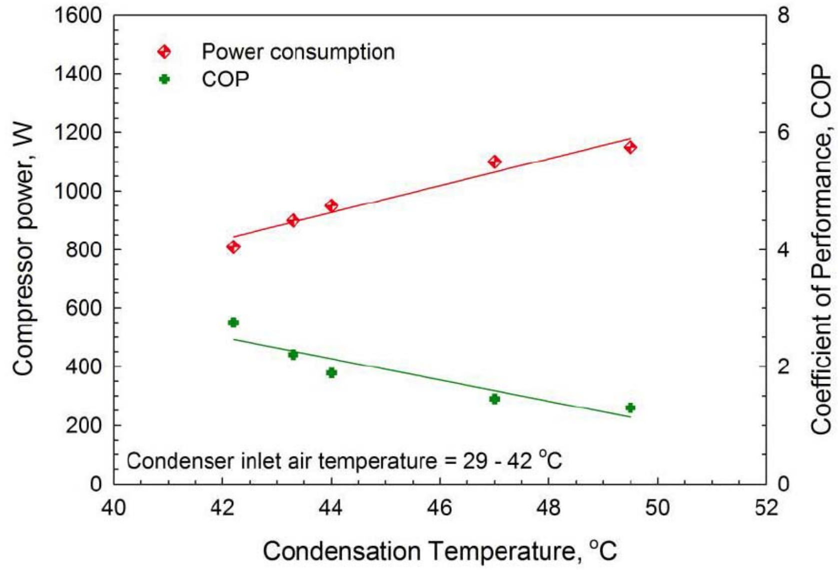


**Figure 5:** Effect of condensation temperature on the power consumption and cycle COP.

increase in power consumption by 36% and a decrease in the cycle COP by about 45%.

### 4.3. Modulation of Condenser Air Flow at Constant Inlet Air Temperature

During these experiments, the temperature of air, which cools the condenser, was kept constant at 36ºC and the airflow through the condenser was varied by controlling the speed of fan manually. Although, the increase of condenser airflow causes an additional increase in electric demand, but the decrease in condensing temperature results in a considerable reduction in compressor's electric demand. This is shown in Figure **6**, as the rate of air flow increases from 0.28 to 0.43 $m^3/s$ the condensing temperature decreases by about 8%. The corresponding reduction in compressor power consumption is about 10%. These findings indicate that the compressor power consumption depends on how the condenser fan is controlled to provide the sufficient airflow for heat rejection for lowering the condensing temperature.

### 4.4. Modulation of Condenser Air Flow at Different Inlet Air Temperature

The condensing temperature can be controlled at a minimum point by continuously modulating the airflow. In these experiments, the condenser fan speed was varied according to the condenser inlet air temperature that represents outdoor air temperature. To show the influence of variable air flow, a comparison between constant and variable condenser fan speed has been presented in Figures **7-9**. Figure **7** illustrates the

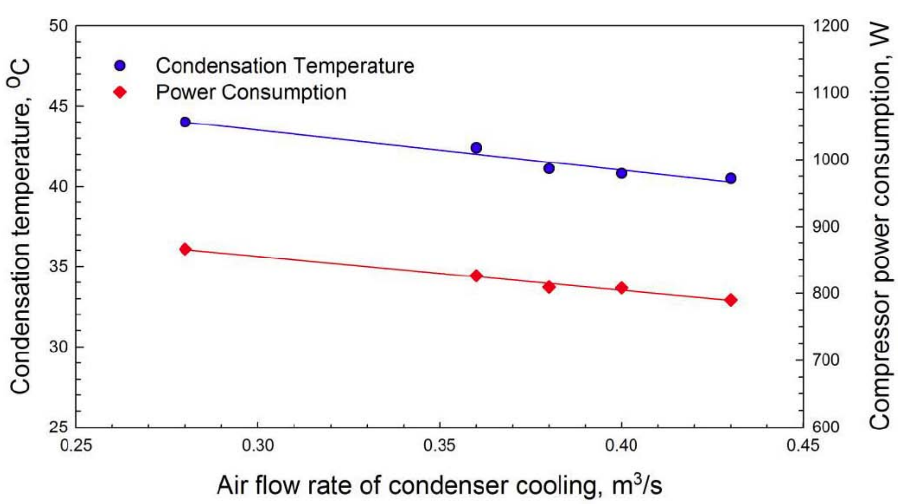


**Figure 6:** Variation of condenser airflow with condensation temperature and compressor power.

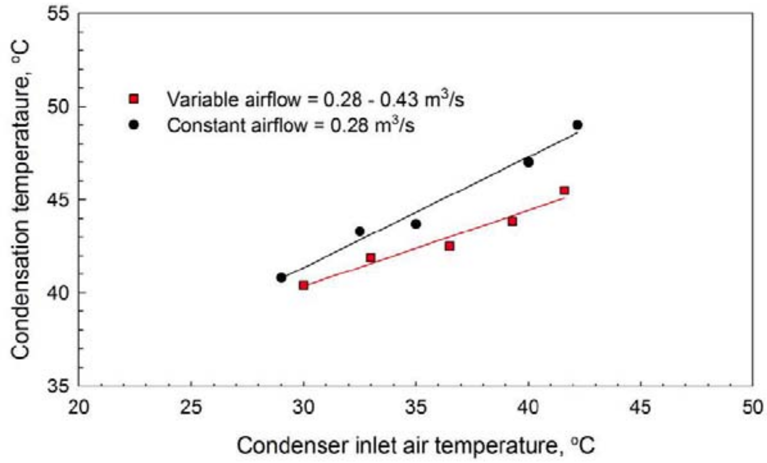


**Figure 7:** Variation of condensing temperature with condenser inlet air temperature.

variation of condensing temperature with the inlet air temperature for constant and variable condenser airflow.

By increasing the rate of airflow through the condenser, the condensing temperature has reduced by 7% (at 42 ºC inlet air temperatures) as shown in the figure. The corresponding reduction in compressor power is recorded in Figure **8**. It is seen from this figure that at 42ºC inlet air temperature, the power consumption has been reduced by about 15%, while at 36ºC inlet air temperature the reduction is about 9%. As mentioned earlier, the increase of heat rejection airflow needs an additional fan electric demand; however, this demand is small compared with the energy saved by the compressor. Moreover, the max power required for condenser fan is only used at the peak of outdoor air.

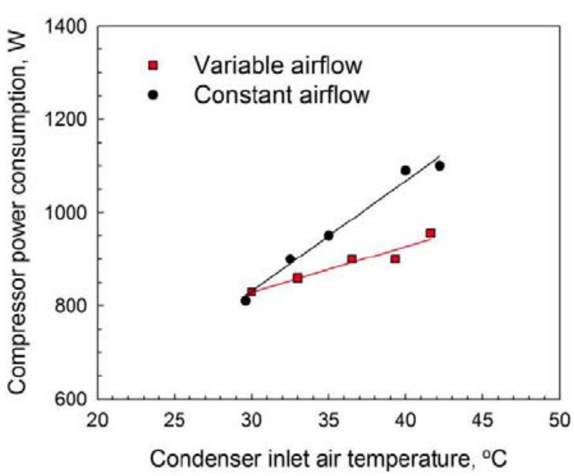


**Figure 8:** Variation of compressor power with condenser inlet air temperature for constant and variable airflow.

Figure **9** reveals the coefficient of performance of the conditioner during constant and variable airflow for condenser fan. It is seen in this figure that the COP of the cycle decreases as the condenser inlet air temperature increase for both cases. This is because the compressor power increases with the increase in condensing temperature. On the other hand, the COP of the cycle has been improvement by about 28% for the variable condenser airflow due to the reduction of compressor power consumption.

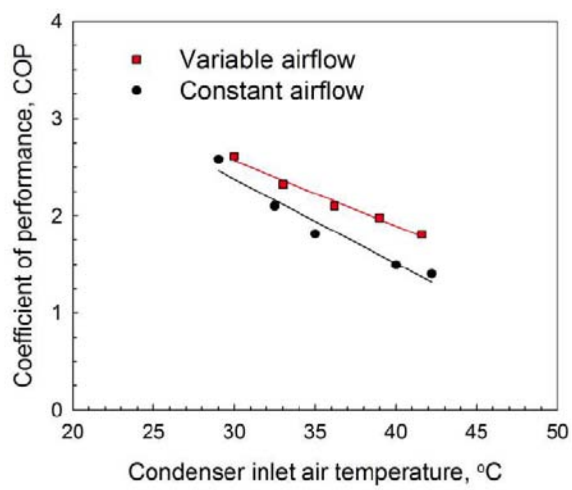


**Figure 9:** Variation of cycle COP with condenser inlet air temperature for constant and variable airflow.

To evaluate the energy saving, the COP of the unit includes the power consumption of the condenser fan and the COP can be defined as:

$$COP_U = Q_{ev} / (W_{comp} + W_{Fan}) \quad (3)$$

As Figure **10** shows, the unit $COP_U$ for variable condenser fan is greater than that for constant speed fan. The profit payback of the present energy saving method can be calculated by the economic analysis. The retrofitting of the present conditioner will be handled in a future work.

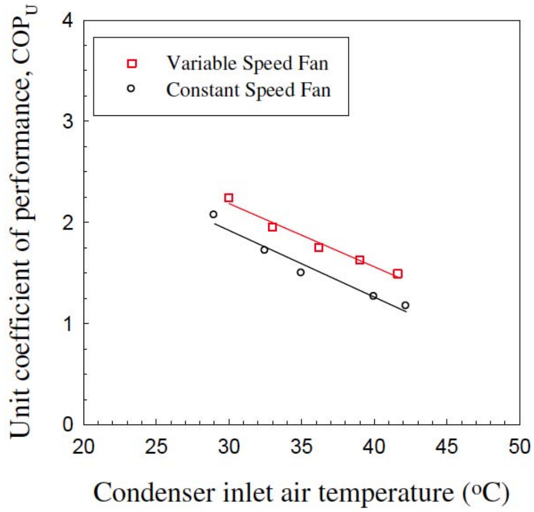


**Figure 10:** Variation of unit $COP_U$ with condenser inlet air temperature.

The study is conducted to compare the present conditioner performance with the performance of water-cooled air conditioner in Ref [6]. As shown in Figure **11**, the COP of the water-cooled air conditioner is higher by about 35% than that for the present conditioner. This is due to the high heat capacity of water compared with the air.

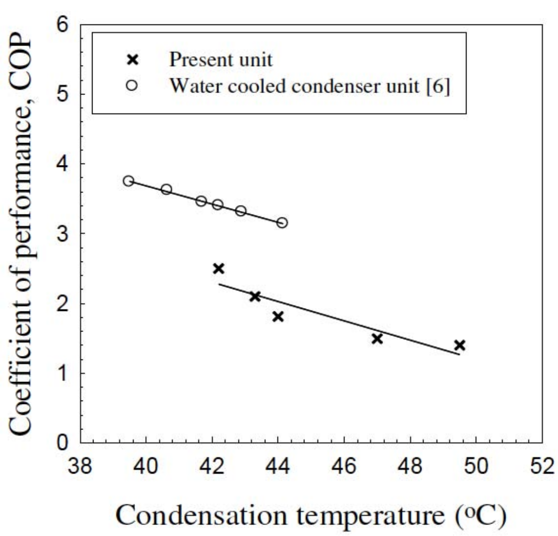


**Figure 11:** Comparison between the COP of the present conditioner and water cooled high performance conditioner in Ref [6].

## 5. CONCLUSIONS

From the above findings, it can be concluded that:

- The power consumption of the compressor was increased by 12% and the cooling capacity was decreased by 25%, when rising the evaporator's inlet air temperature from 26 to 35 ºC.
- The cooling capacity of the evaporator was decreased by 32% when rising the condenser entering air temperature from 30 to 42ºC, while the compressor power consumption was increased by about 36 %.
- At constant inlet air temperature, 10 % reduction in the compressor power consumption has been obtained when increasing the condenser cooling air flow by about 1.5 times.
- For variable speed condenser fan, it is found that the compressor power has been reduced by 15% at 42ºC condenser entering air temperature; while at 36ºC the reduction is about 9%.
- The use of variable speed condenser fan causes an increase in the COP of the conditioner by 28% at 42ºC condenser entering air temperature.

Variable speed motor is recommended for the condenser fan with advanced control to accommodate the variation of outdoor air temperature for tracking and adjusting the condensing temperature.

## NOMENCLATURE

| | | |
|---|---|---|
| COP | coefficient of performance | |
| H | refrigerant enthalpy | $kJ.kg^{-1}$ |
| $m_{ref}$ | refrigerant flow rate | $kg.s^{-1}$ |
| P | pressure | kPa |
| $T_{ev}$ | evaporation temperature | °C |
| $T_{cond}$ | condensation temperature | °C |
| $Q_{ev}$ | evaporator cooling capacity | kW |
| $W_{comp}$ | compressor power consumption | kW |
| $W_{Fan}$ | condenser fan power | kW |

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Received on 17-11-2019 Accepted on 04-12-2019 Published on 30-12-2019

DOI: http://dx.doi.org/10.15377/2409-5818.2019.06.4