# Performance Enhancement of an Air Cooled Air Conditioner with Evaporative Water Mist Pre-cooling

**Assistant Professor Dr. Najim Abid Jassim**
Mechanical Department - Engineering College - Baghdad University
Email: najmosawe @yahoo.com

## ABSTRACT

The present paper deals with experimental investigation of the performance of air cooled split air conditioner, with evaporative water mist pre cooling to increase the cooling capacity and reduce the consumption power under hot and dry climate. This investigation considers how the performance can be enhanced by using water mist to pre-cool ambient air entering the condensers by adiabatic cooling process which depends on the ambient air wet bulb temperature; as well the condensing temperature and condensing pressure will be decreased accordingly. So the cooling capacity would be increased and consumption power would be decreased, consequently the energy ratio, EER would be improved. The performance of air cooled air conditioner with water mist pre cooling; ECAC was compared to the performance of air cooled air conditioner, ACAC which tested under the same ambient condition that is ranged from 25$^{o}$C to 52$^{o}$C. Test results show that ECAC operating at EER of 10.5 BTV/W. The ECAC had an EER of 47 % higher than that of ACAC under the same and most serve hot and dry condition of 52$^{o}$C and 10% relative humidity.

**Keywords:** air cooled air conditioner, thermal performance, evaporative water mist pre-cooling.

# تحسين الاداء الحراري لمكيف هواء مكثفه مبرد بالهواء مع تبريد مسبق بمرذاذ مائي تبخيري

**ا.م.د. نجم عبد جاسم**
قسم الميكانيك - كلية الهندسة - جامعة بغداد

## الخلاصة

يتعامل البحث الحالي مع التحري التجريبي للاداء الحراري لمكيف هواء نوع منفصل مكثفه مبرد بالهواء مع مرذاذ مائي في عملية تبريد اولي للهواء الخارجي الداخل للمكثف لغرض زيادة السعة التبريدية وخفض الطاقة المستهلكة في جو حار وجاف. يوضح هذا التحقق التجريبي كيف يمكن تحسين الاداء الحراري عند استعمال مرذاذ مائي كمبرد اولي لخفض درجة حرارة الهواء الخارجي قبل الدخول الى المكثف بعملية تبريد اديباتي تعتمد على درجة حرارة البصلة الرطبة للهواء كذلك بموجبها يتم خفض درجة حرارة وضغط التكثيف وفقا لذلك. لذا ستزداد السعة التبريدية وستنخفض الطاقة المستهلاكة وبالتالي ستتحسن نسبة كفاءة الطاقة. تم مقارنة الاداء الحراري لمكيف هواء مكثفه مبرد بالهواء مع مرذاذ مائي مع الاداء الحراري لمكيف الهواء مكثفه مبرد بالهواء ACAC والتي اختبرت في نفس ظروف الجو الخارجي عند درجات حرارة هواء خارجي مداها بين 25 $^{o}$م و 52 $^{o}$م. بينت نتائج الاختبار عند الظروف الاساسية بان ECAC تعمل بنسبة كفاءة طاقة EER مقدارها 10.5. ان نسبة كفاءة الطاقة EER لمكيف الهواء ECAC في ظروف جو سائدة حارة وجافة عند درجة حرار 52 $^{o}$م ورطوبة نسبية 10% اعلى بمقدار 47 % من مكيف الهواء ذو مكثف مبرد بالهواء في نفس الظروف.

**كلمات رئيسية:** مكيف هواء بمكثف مبرد بالهواء، اداء حراري، تبريد اولي بمرذاذ مائي تبخيري.

## 1. INTRODUCTION

Air-cooled air conditioners are widely used to provide space cooling in air-conditioned buildings due to their flexibility and yet pragmatic and simple energy efficient measures for them are still lacking. The vapor compression refrigeration, VCR is widely used in various cooling applications.

The coefficient of performance, COP of the VCR cycle depends upon various parameters like sub cooling, superheating, suction & discharge pressure of the compressor. COP is also greatly affected due to power consumption of the compressor as it is a major power-consuming element. Increase in the condenser temperature leads to increase the condenser pressure and hence compressor work. Also the increase in condenser pressure causes a reduction in liquid content in the evaporator; consequently the cooling capacity of the cycle will be decreased. So the COP and EER of the system considerably decrease with increasing condenser pressure. The temperature of entering air cooled condenser in a VCR system depends on the ambient air temperature.

Evaporative water mist can reduce the ambient air temperature before entering the air cooled condenser from its dry bulb temperature to approximately its wet bulb temperature. Therefore it is definitely the heat exchange in the condenser will be enhanced, consequently the energy efficiency of the condenser and the coefficient of performance of air conditioner will be improved **ASHRAE, 2009, Birangane and Patil, 2014**.

**Hwang et al., 2001** conducted an experiment on the air cooled condenser and water cooled condenser of a household refrigerators. The water cooled condensers were utilized as a tube in the heat exchanger which was known as tube heat exchanger and had inlet for the purpose of cooling water and hot water was collecting at the exit. The air cooled condenser increased the compressor work that's why COP was higher in water cooled condenser case than air cooled condenser.

**Radermacher et al., 2001** investigated evaporative cooling and conventional cooling for a split heat pump system. The spilt heat pump consists of two separate sections, one as indoor loop and the other as outdoor chamber for maintaining air temperature in each section. He built wetted rotating disks into the front of air cooled condenser onto an existing split heat pump system as evaporative pre-cooling. The final results showed improved steady state performance; a higher capacity of COP by 11.1 to 21.6%.

**Hosoz and Kilicarslan, 2004** performed an experiment on the performance comparison of the air cooled, water cooled, and evaporative cooled condenser used in the refrigeration system. For this, a model was developed in which first air cooled condenser was used and result showed less COP. So, test was performed on water cooled condenser which was implemented to take the heat through water at the condenser which was thrown into the surrounding air. After that, the investigation was done on evaporative condenser. It was found that the water cooled condenser improved the refrigeration effect and COP by 2.9-14.4% and 1.5-10.2% respectively, when compared with evaporative pre-cooling condenser. Furthermore, the refrigerating effect and COP of a condenser with evaporative cooling were 31% and 14.3% higher than that of air cooled respectively.

**Hajidavalloo, 2007** investigated incorporation of evaporative cooling in the condenser of window-air-conditioner. An air cooled conditioner was equipped with evaporative pads pre-cooling system and spraying water mist on the pads to cool down the ambient air before entering the condenser. The test results present an enhancement in the thermodynamic characteristics of new system. The consumption power was saved by 16% and the coefficient of performance was improved by 55%.

**Nasr and Hassan, 2009** studied a renewal condenser for residential refrigerator. He wrapped the air cooled condenser with wetted cloth sheets to suck the water from a water basin by capillary effect as evaporative pre-cooling. Test results showed that the condenser entering air dry bulb temperature was dropped from the ambient air temperature by up to 9.4℃. So the COP was increased by 18.6%.
The studies of **Yang et al.** and **Yu and Chan, 2009** are based on the application of water mist as evaporative pre-coolers associated with air-cooled chillers of 1105 kW rated cooling capacity to pre-cool ambient air before entering the condenser under climate of Hong Kong. They concluded that this application lower the chiller power by about 15%.
**Hajidavalloo and Eghtedari, 2010** investigated about the application of evaporative cooled air condenser instead of air cooled condenser to solve the problem of maintaining higher COP in hot and dry regions. He integrated an evaporative pre-cooling and with air-cooled split air conditioner to indicate its effect on thermodynamic characteristics of a new cycle. Test results showed that application of new system has significant effect on the performance enhancement of the cycle with a rate increase with increasing ambient air temperature.
**Faramarzi et al., 2010** examined the performance of an evaporative pre-cool condenser-type roof top packaged air conditioner of 10 tons rated cooling capacity under different USA climates. The variations in cooling capacity, consumption power, energy efficiency ratio, and water consumption under hot and dry conditions were tested and presented. Experimental results show that the ECAC operate at an EER of 13.5 Btu/W. The EER of ECAC was then compared to the EER of air-cooled condenser type air conditioner, ACAC under similar test conditions. The EER of ECAC was found higher than that of ACAC by about to 51% under the approximately same conditions of 46°C dry bulb temperature and 35°C wet-bulb temperature.
**Singh et al., 2016 reviewed** a study on performance comparison between air cooled and water cooled condenser in compression refrigeration. They built an evaporative pad in front of condenser of forced air cooling to improve the energy efficiency of condenser. Experimental results indicated that the cooling capacity was increased by 2.9 to 14.4 % and the coefficient of performance is enhanced by 1.5 and condenser pre cooling means higher drop in condenser inlet air temperature when compared with air cooled and 10.2 % with respect to evaporative condenser. Due to higher heat exchange and efficiency of evaporative and condenser pre cooling means higher drop in condenser inlet air temperature when compared with air cooled and evaporative condenser.
In the study of **Torgal et al., 2016,** the performance of air cooled conditioner with water mist system was tested. The vibrations of cooling capacity and consumption power due to effects of condenser inlet air temperatures was investigated and presented. They coupled the water mist system with the air cooled conditioner as a pre-cool air to increase the cooling capacity, and decrease the compressor power. Experimental results showed that due to the coupling of water mist with air cooled condenser, the cooling capacity of the air-cooled, air conditioner can be increased by 17.5%, and the consumption power can be decreased by 15.5%. So that the COP of the air cooled conditioner could improve by 37%, when the water mist system used as pre-cooling.

The objective of this study was to investigate experimentally the thermal performance of water mist pre-cool air cooled air conditioner, ECAC under Iraqi climate. A water mist assisted air cooled air conditioner was designed, built, instrumented and tested. Experimental tests were conducted by varying the condenser inlet air temperature and water mist spraying rate to investigate their effects on cooling capacity, consumption power and the energy efficiency ratio of air conditioner.

## 2. SYSTEM DESCRIPTION

A single-stage vapor compression cooled split air conditioner operates with R134 as refrigerant coupled with water mist pre-cooling system is designed, built, instrumented and tested in order to be used for conducting experiments.

Air cooled condenser is refrigerant to air heat exchanger, where heat is transferred sensibly from the refrigerant of condenser high pressure / temperature to forced flowing ambient air depending on the ambient dry bulb temperature.

Evaporative water mist pre-cool condenser is primarily driven by the latent heat of water vaporization depending on the ambient wet bulb temperature. The water mist can be easily vaporized by the ambient air before entering the condenser. The reduction in the temperature of ambient air follows the adiabatic cooling process with constant specific enthalpy. This reduction in the condenser inlet air temperature compared to the ambient temperature causes a decrease in refrigerant condensing temperature and pressure.

**Fig. 1** shows two cases of the refrigerant cycle of air conditioner. Case 1-2-3-4-1 refers to air cooled condenser and case 1'-2'-3'-4'-1' refers to water mist pre-cool condenser. It is clear that the consumption power is decreased with decreasing the condensing pressure, while the refrigeration effect is increased. So the coefficient of performance of air conditioner will definitely be increased.
A schematic diagram of the vapor compression refrigeration cycle with all high precision calibrated sensors/transducers was used for measuring all operating is presented in **Fig. 2.**
The experimental test rig shown in **Figs 3, 4** has rated cooling capacity of 3.51 kW for condenser and evaporator inlet air temperatures of 35 and 24$^{o}$C respectively. It consists of major components, namely a compressor, DX condenser, thermostatic expansion valve and DX evaporator. It is manufactured in China by Discovery Trade Mark with the specifications tabulated in **table.1**.
The condensing unit was equipped with evaporative water mist system. The water mist system consisted of high pressure pump, water filter, copper piping, atomization nozzle and water storage tank. For water consumption measurements a small connection tube at the bottom of the water tank to pellucid flexible tube which is fixed at the tank wall from the outside and practically calibrated and pointed by using a laboratory calibrated carafe to show the change in tank containing volume in liters. The water mist system was used to deliver water at rate of 0.17-0.5 L/min and pressure of 70-100 bars. It is manufactured in Italy by Inter Pump Group with the specifications tabulated in **table.2**.

The experimental test rig is equipped with a calibrated thermocouples type T and relative humidity sensors, H with uncertainties of ± 0.2, and ± 0.1 respectively. The thermocouples are fixed at the condenser and evaporator to measure the refrigerant condensing and evaporation temperatures, Also thermocouples and relative humidity devices are fixed at the inlets and outlets of condenser and evaporator to determine the enthalpy values of air.
A calibrated refrigerant rotameter is fixed at the liquid line to measure the mass flow rate with uncertainty of ± 0.5 Kg/h. The rig is equipped with a calibrated watt meter to measure the consumption power. All tests were performed in an identical manner and at steady state. All experiment tests were conducted at approximately constant room temperature of 25 $^{o}$C and repeated with varying the condenser inlet air temperature from 25 to 52 $^{o}$C.

## 3. SYSTEM ANALYSIS

### Air cooled air conditioner, ACAC

To investigate the performance of air condition on operated parameters must be measured such as consumption power, $W_C$. The supply and return evaporator air temperatures are $T_{e,s}$ and $T_{e,r}$, entering and leaving condenser air temperatures are $T_{c,e}$ and $T_{c,l}$ . The refrigerant condensing and evaporative temperatures are $T_{cd}$ and $T_{ev}$.

The cooling capacity of air conditioner, $Q_L$ is obtained by using the following equation:

$$Q_L= \rho_a V_{ev} (h_{e,r}- h_{e,s}) \quad (1)$$

Where: $\rho_a$ is the density of air, kg/m$^3$ and $V_{ev}$ is the evaporator fan flow rate of air, m$^3$/s.

and $h_{e,r}$ and $h_{e,s}$ are enthalpies of the air at evaporator inlet and outlet, respectively, kJ/kg.

The heat rejection by the condenser, $Q_H$ is obtained by using the following equation:

$$Q_H= Q_L+ W_C \quad (2)$$

The COP of air conditioner is the cooling capacity, $Q_L$ over consumption power, $W_C$, as follow:

$$COP = Q_L / W_C \quad (3)$$

The EER of air conditioner is the ratio of cooling capacity in Btu to consumption power in watt as:

$$EER = 3.418\ Q_L / W_C \quad (4)$$

The cooling capacity $Q_{L,}$ consumption power, $W_C$ and heat rejected, $Q_H$ are varied with varying the condensing temperature, $T_{cd}$.

### Air conditioner with water mist, ECAC

When a water pump operates to spray water mist, the ambient air temperature $T_{db}$, follows the adiabatic cooling process and reduced to $T_{db}^{/}$. And the humidity ratio is increased from $W_{db}$ to $W_{db}^{/}$. This is dependent on air its mass rate and mist spraying rate as given by:

$$m_{mist}= \rho_a V_{cd}\ \Delta W \quad (5)$$

Where: $\rho_a$ is the density of air, kg/m$^3$ and $V_{cd}$ is the condenser fan flow rate of air, m$^3$/s.

and $\Delta W$ is the humidity ratio rise ($\Delta W= W_{db}^{/} - W_{db}$) water vapor to air mass ratio, $kg_v/kg_a$

All the measured data taken from experimental tests were used as primary given data in computing secondary output parameters such as: cooling capacity, coefficient of performance, and the energy efficiency ratio.

## 4. RESULTS AND DISCUSSIONS

In order to enhance the thermal performance of air cooled air conditioner a water mist system is coupled with air cooled air condenser. By the adiabatic cooling process taking place in the evaporative water mist pre-cooling, the temperature of condenser inlet air will be decreased compared with the ambient temperature, as well the condensing temperature and condensing pressure will be decreased accordingly.
The baseline reveals a cooling capacity, consumption power and energy efficiency ratio at ambient temperature of 35$^{o}$C. The normalization is the ratio of test data at any ambient temperature to its value at baseline test temperature.
**Fig. 5** illustrates the variation in cooling capacity of air conditioner with varying the condenser inlet air temperature. As can be seen the normalized cooling capacity increased as the condensing temperature decreased. This is due to the increase in refrigeration effect and compressor volumetric efficiency.

The cooling capacity was normalized based on the baseline cooling capacity at temperature of 35$^{o}$C. The normalized cooling capacity of ECAC was found over by 5% than that of baseline at 25$^{o}$C and lower by 7% than that of baseline at 52$^{o}$C. And the normalized cooling capacity of ACAC was found over by 7% than that of baseline at 25$^{o}$C and lower by 9% than that of base line at 52$^{o}$C.

**Fig. 6** shows the variation in consumption power of air conditioner with varying condenser inlet air temperature. As can be seen the normalized consumption power decreased as the condensing temperature decreased. This is due to the decrease in condensing pressure and compression ratio.

The consumption power was normalized based on the baseline consumption power at temperature of 35$^{o}$C. The normalized consumption power of ECAC was found over by 18% than that of baseline at 52$^{o}$C and lower by 6% than that of baseline at 25$^{o}$C. And the normalized consumption power of ACAC was found over by 24% than that of baseline at 52$^{o}$C and lower by 7% than that of baseline at 25$^{o}$C.

**Fig. 7** shows the influence of condenser inlet air temperature on the energy efficiency ratio, EER. When the condensing temperature decreases the refrigeration effect would be increased, which overcomes the increase in consumption power, so the EER would be improved.

The EER was normalized based on the baseline EER at temperature of 35$^{o}$C. The normalized EER of ECAC was found over by 7% than that of baseline at 52$^{o}$C and lower by 3% than that of baseline at 25$^{o}$C. And normalized EER of ACAC was found over by 14% than that of baseline at 25$^{o}$C and lower by 24%than that of baseline at 52$^{o}$C.

**Fig. 8** shows a comparison between ACAC and ECAC regarding the EER of the refrigeration cycle. The EER of ECAC was found higher by about 21.7% and 49.9% than that of ACAC at 25$^{o}$C and 52$^{o}$C respectively.

**Figs. 9 to 11** illustrate the ACAC and ECAC unit's variation in performance (cooling capacity, power consumption and EER) across a range of climate conditions in terms of dry bulb and wet bulb temperatures that are mentioned in column charts and represented by the following ambient condition index:
**1:** 25,18; **2:**30,20; **3:** 35,21.5; **4:** 40,23; **5:** 46, 24; **6:** 52, 25 $^{o}$C dry bulb and wet bulb temperatures respectively.
Cooling capacity was as low as 1.04 and 1.205 kW at 52$^{o}$C respectively, and as high as 1.35 and 1.5 kW at 25$^{o}$C respectively.
Total power consumption was as high as 0.65 and 0.535 kW at 52$^{o}$C and as low as 0.44 and 0.4 kW at 25$^{o}$C respectively.
EER were as low as 5.13 and 7.69 at 52$^{o}$C respectively, and as high as 10.25 and 12.47 at 25$^{o}$C respectively.
**Fig. 12** illustrates the variation of water consumption by evaporation in ECAC unit with increasing condenser inlet air temperature. Water consumption was as high as 0.05 kg/s at 52$^{o}$C, and as low as 0.0225 kg/s at 25$^{o}$C.

**Fig. 13** shows a comparison between the present work and results of **Faramarzi, 2010.** It is clear that the EER of air cooled air conditioner coupled with water mist pr-cooling is higher than that of conventional air cooled air conditioner. This is due to the adiabatic cooling of ambient air before entering the condenser, which is taken in water mist system. The average deviation between the present work and results of **Faramarzi, 2010** regarding the EER of ECAC is 23.2% due to tests done under different conditions.

## 5. CONCLUSIONS

In this study the application of water mist system pre-cooling have been investigated for air cooled split air conditioner under hot and dry climate condition. The applying of adiabatic cooling with air cooled condenser would be more cooling effect and thermal performance enhancement would be more significant if the air condition operates in hot and dry ambient conditions. From the above findings, it can be concluded that:

- The performance enhancement of ECAC compared to conventional air-cooled units is significant in hot and dry conditions.
- The normalized consumption power of ECAC was saved by 13.7 %, while the normalized cooling capacity was enhanced by 15.9% compared with ACAC under the hot and dry climate condition of 52$^{o}$C.
- The EER of ECAC was improved by an average of 49.9 % compared with ACAC under the same hot and dry climate condition of 52$^{o}$C.
- ECAC consumes 0.0335 liter/s/kW of cooling capacity by evaporation in adiabatic cooling process at 35$^{o}$C and 25$^{o}$C dry and wet bulb temperatures.
- Overall, the test results indicate that the ECAC provides more efficient compared to conventional air-cooled units in all climate conditions.

## NOMENCLATURE

h enthalpy, kJ/kg

m mass flow rate, kg/s

P pressure, N/$m^2$

$Q_L$ cooling capacity, kW

$Q_H$ heat rejection, kW

T temperature, °C

V volume rate of air, $m^3$/s

W moisture content, $kg_v/kg_a$

$W_C$ compressor work, kW

### Greek symbol

ρ density, kg/$m^3$

### Subscripts

a air

cd condenser

c,e entering air to condenser

c,l leaving air from condenser

ev evaporator

e,r return air to evaporator

e,s supply air from evaporator

db dry bulb

mist water mist

### Abbreviations

ACAC air cooled air conditioner

COP coefficient of performance

DB dry bulb

DX direct expansion

ECAC evaporative cooled air conditioner

EER energy efficiency ratio

WB wet bulb

RH relative humidity

VCR vapor compression refrigeration

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**Table 1.** Split air conditioner specifications**.**

| Split air conditioner model DAC-12000 HC2 | | | |
|---|---|---|---|
| Cooling capacity | 3510 watt | Refrigerant | R22 |
| Condenser flow rate | 900 $m^3/h$ | Input power | 1250 watt |
| Evaporator flow rate | 450 $m^3/h$ | Electric supply | 1pH-50Hz-220V |

**Table 2.** High pressure pump specifications.

| High pressure pump model M51012 | | | |
|---|---|---|---|
| Pump pressure | 70 - 100 bar | Input power | 0.55 kw, 1450 rpm |
| Pump flow rate | 0.25-1 L/min | Electric supply | 1pH-50Hz-220V |

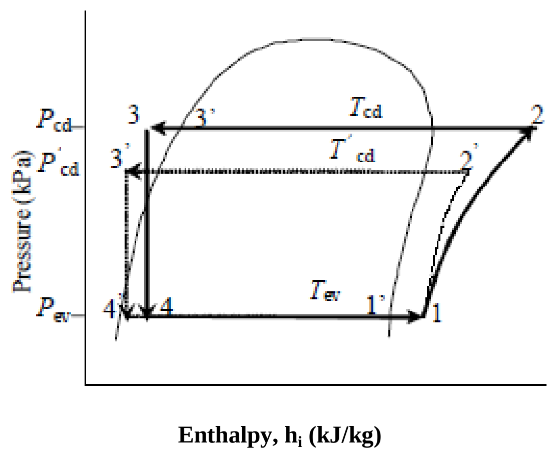



**Figure 1.** Effect of condensing temperature on VCR cycle.

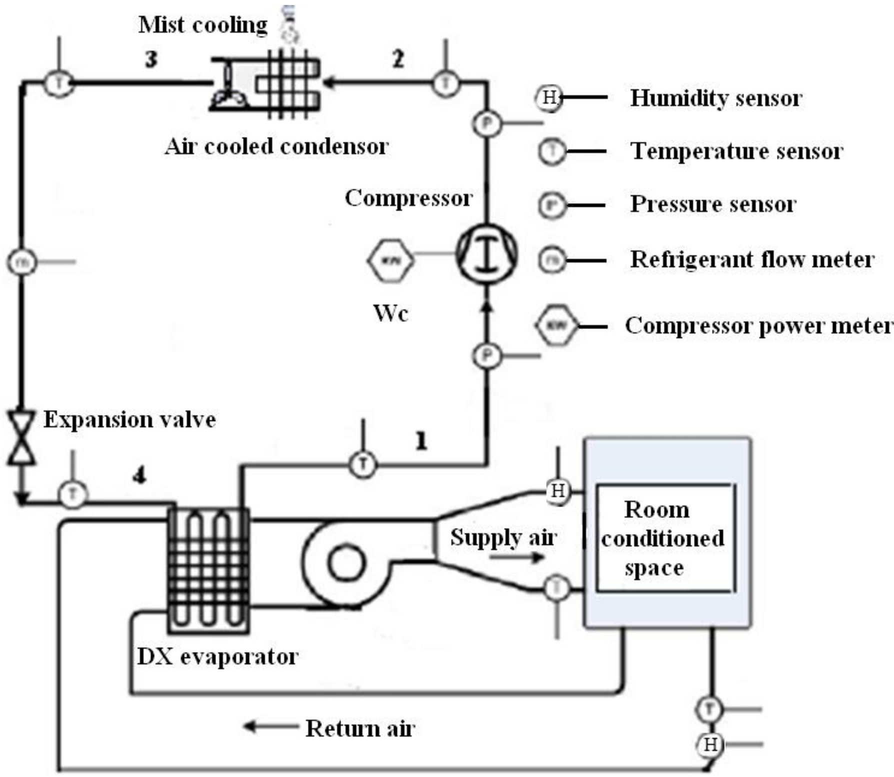



**Figure 2.** Schematic diagram of VCR with instrumentations.

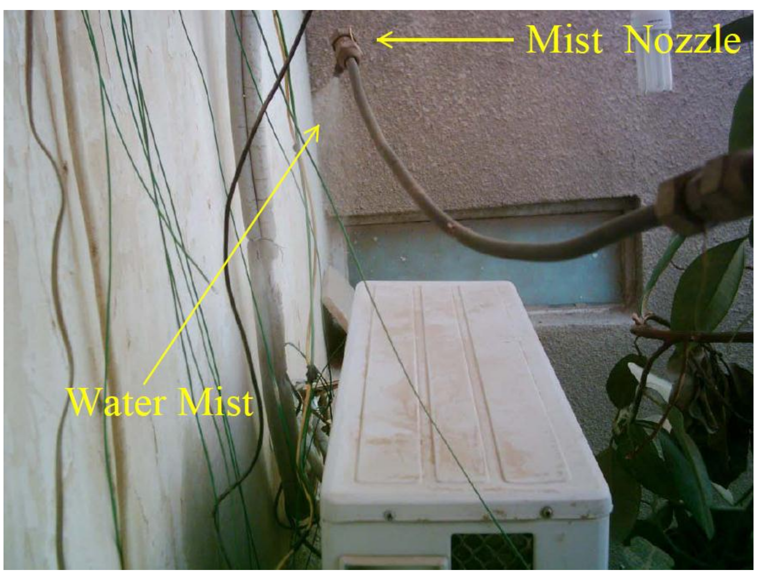
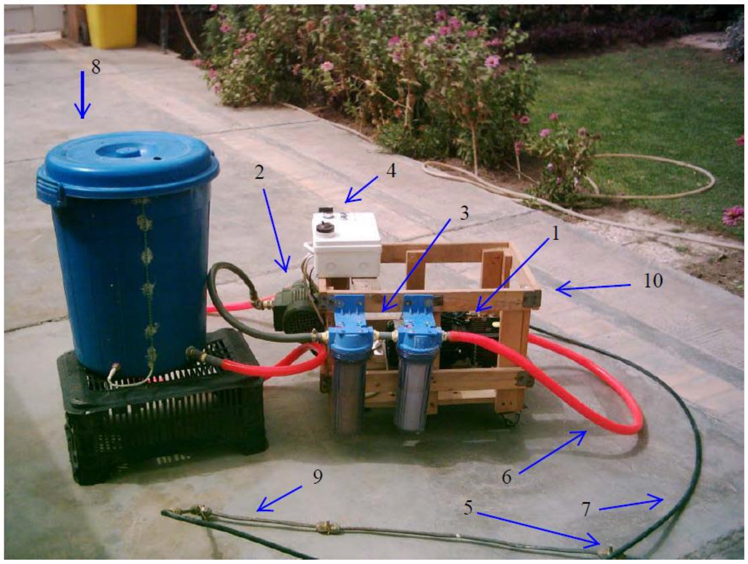



**Figure 3.** Air conditioner with water mist, ECAC.




| | | | |
|---|---|---|---|
| 1 | High pressure pump | 6 | Low pressure elastic pipe |
| 2 | Low pressure pump | 7 | High pressure hose |
| 3 | 5 microns water filter | 8 | Water tank |
| 4 | Operating electrical board | 9 | Copper Mist network |
| 5 | Mist nozzle | 10 | Wood frame |

**Figure 4.** Water mist system.

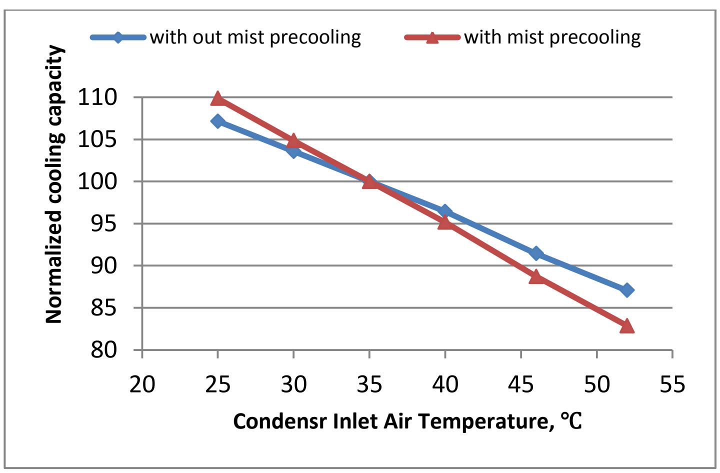



**Figure 5.** Normalized comparison of cooling capacity between ACAC & ECAC**.**

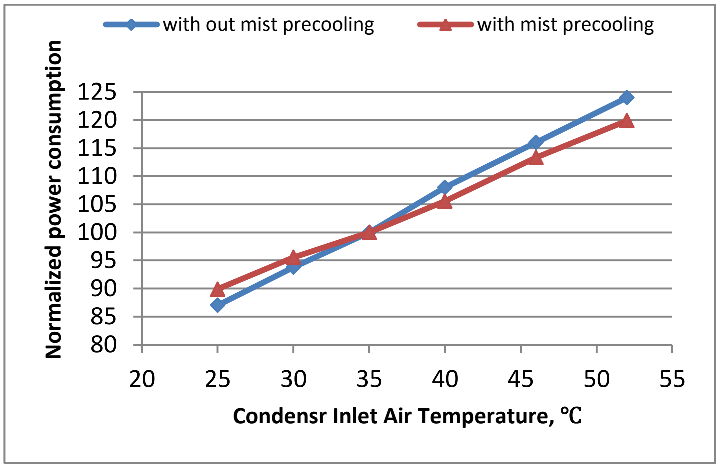



**Figure 6.** Normalized comparison of power consumption between ACAC & ECAC.

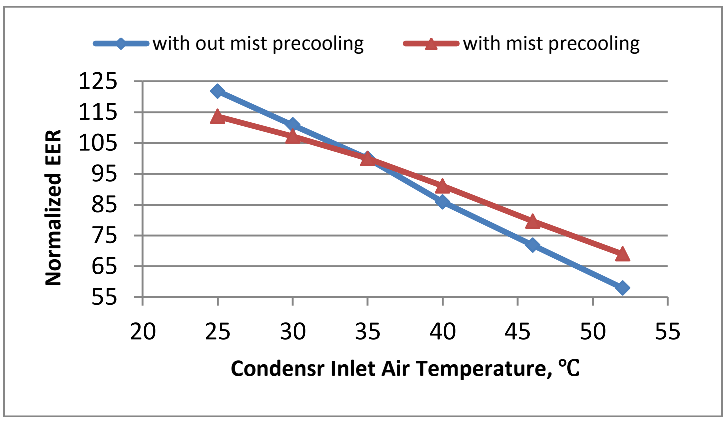



**Figure 7.** Normalized comparison of EER between ACAC & ECAC**.**

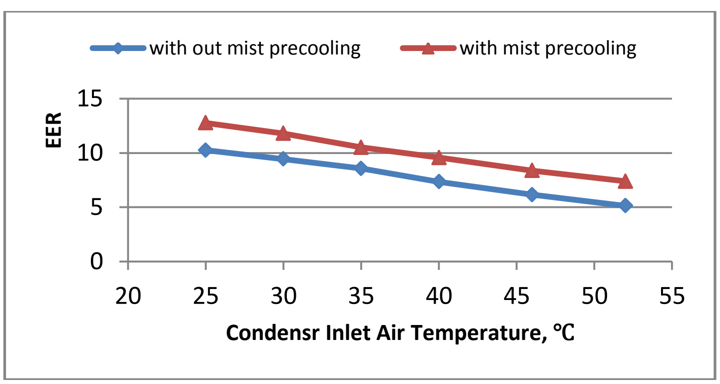



**Figure 8.** Comparison of EER between ACAC & ECAC**.**

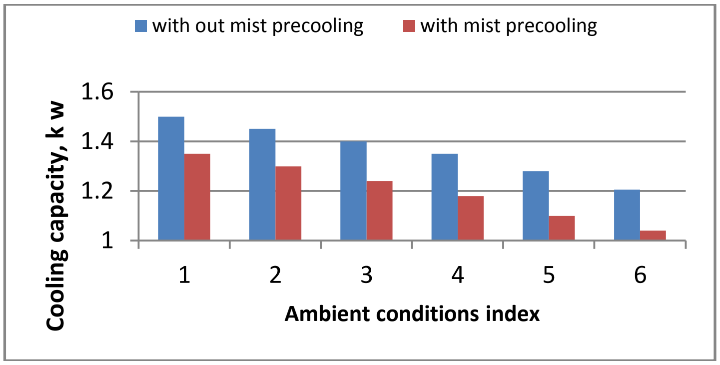



**Figure 9.** Comparison of cooling capacity between ACAC & ECAC.

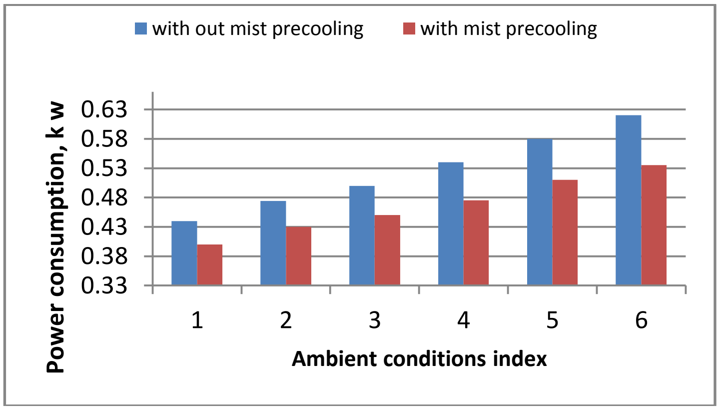



**Figure 10.** Comparison of power consumption between ACAC & ECAC.

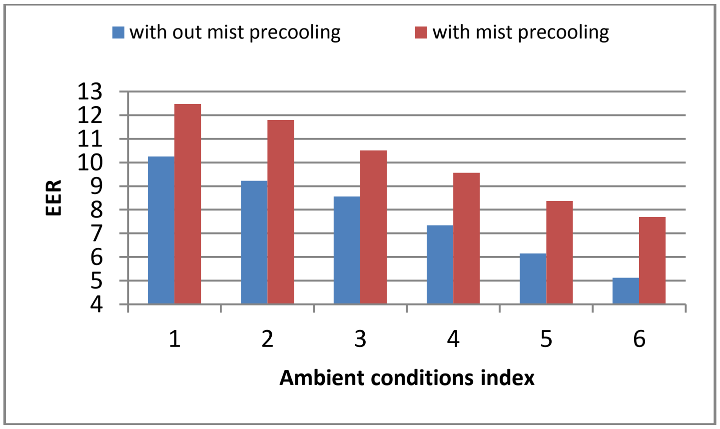



**Figure 11.** Comparison of EER between ACAC & ECAC.

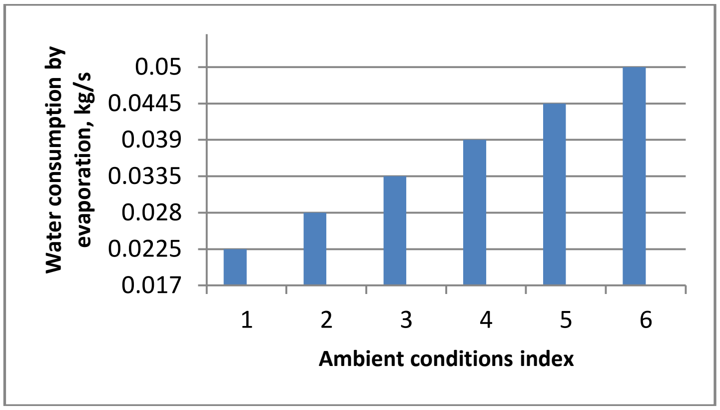



**Figure 12.** Water consumption by evaporation by ECAC**.**

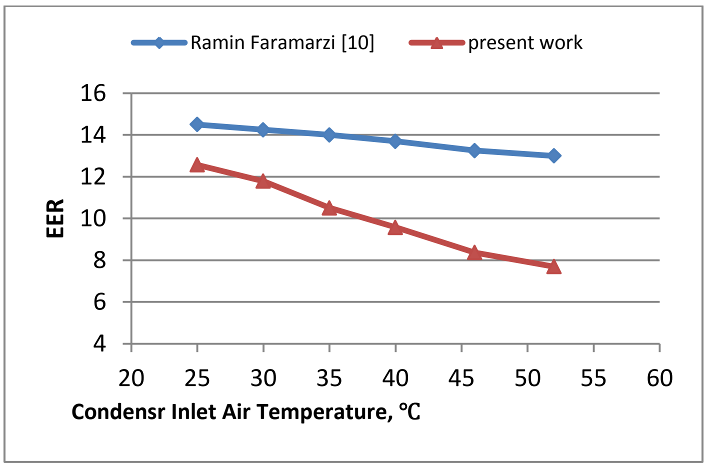



**Figure 13.** Comparison between present work & Faramarzi, 2010 for the EER of ECAC.