Experimental Investigation of the Performance and Energy saving of Air Conditioning Unit with Indirect Evaporative Cooled Condenser

A THESIS

SUBMITTED TO THE DEPARTMENT ENGINEERING OF POWER MECHANICS TECHNIQUES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF THERMAL TECHNOLOGIES IN ENGINEERING OF POWER MECHANICS TECHNIQUES
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BY

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بســــــــــــــم الله الرحمن الرحيم

هُوَ الَّذي جَعَلَ الشَّمسَ ضِياءً وَالقَمَرَ نورًا وَقَدَّرَهُ
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Abd-Albasit Thary Yousif

2022

SUPERVISORS CERTIFICATION

We certify that this thesis titled "**Experimental investigation of the Performance and energy saving of Air Conditioning Unit with indirect Evaporative Cooled Condenser**'' submitted by **Abd-Albasit Thary Yousif** has been prepared under our supervision at the Department of Mechanical Engineering Techniques of Power, College of Technical Engineering-Najaf, AL-Furat Al-Awsat Technical University, as partial fulfilment of the requirements for the degree of Master of Techniques in Thermal Engineering.

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We certify that we have read the thesis entitled “**Experimental investigation of the Performance and energy saving of Air Conditioning Unit with indirect Evaporative Cooled Condenser**’’ submitted by **Abd-Albasit Thary Yousif** and, as examining committee, examined the student’s thesis in its contents. And that, in our opinion, it is adequate as a thesis for the degree of Master of Techniques in Thermal Engineering.

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ABSTRACT

One of the most important obstacles in the use of refrigeration and air conditioning units is their high-energy consumption throughout the months of the year. But in the summer seasons, and when the temperature reaches more than 40 °C, these units drain a greater amount of energy in the rest of the seasons. While the parameters of these units decrease significantly also in the summer season.

A split type air conditioning unit with a capacity of 1 ton was used in the practical part. Also, a cellulose pad of different thicknesses (3.5, 7) cm was used to cool the air passing through the condenser with a water flow rate of (100, 125, 150) liters / h.

In this study, many practical experiments were investigated, which in turn increased the performance parameters, also the energy savings when using the indirect evaporative condenser. Where an increase in the performance factor was obtained by 21.8% when using an evaporative condenser with a cushion thickness of 3 cm and a volumetric water flow of 150 l/h with energy savings of 14.2%. While the percentage increase in the performance factor decreased to 17.2% with energy savings of 14.6 when using an evaporative condenser with a pillow thickness of 7 cm and a volumetric water flow of 100 liters / h. Then, the best results were achieved when using an evaporative condenser with a pillow thickness of 5 cm and a volumetric water flow of 100 liters / h, to reach an increase in the performance factor by 25.2%, with an energy saving of 13.2%.

CONTENT

NOMENCLATURE

Symbol	Definition	Unit
CP	Specific heat at constant pressure of moist air	(J/kg K)
h	Enthalpy	(J/kg)
I	Current	Ampere (A)
$\dot{m}$	mass flow rate	(kg/s)
Qc	Condenser capacity	kW
Qe	evaporator capacity	kW
RE	Refrigerant effect	kW
RH	Relative humidity	%
T	Temperature	^{o}C
T_{wbt}	Wet bulb temperature	^{o}C
T_{dbt}	Dry bulb temperature	^{o}C
$\dot{V}$	Volume flow rate	(lit/h)
V	Voltage	Volt (V)
W	Work compressor	kW
Abbreviations		
HVAC	Heating, ventilating, and air conditioning	
comp	Compressor	
Cond	Condenser	

COP	coefficient of performance
evap	Evaporator
EES	Engineering Equation Solver
TR	Ton Refrigerant
AC	Alternating current

Chapter one

Introduction

CHAPTER ONE

Introduction

1.1 Background

The air conditioning unit is considered one of the basic requirements today. Using to comfort space for the occupants and to the devices, that operate according to certain operating conditions through air purification or humidity control[1]. In addition to the basic function that includes regulating the temperature of the place to be conditioned. Air conditioning systems work by cooling or heating the conditions space, through heat exchange [2]. The heat exchange happens between the ambient air and the refrigerant indirectly. This heat exchange is done through a heat exchanger that is selected according to the type and size of the space to be adapted to suit the size of the building [3] [4].

The air conditioning unit usually consists of four basic parts that include: compressor, condenser, expansion valve, evaporator[5][6]. The compressor is the heart of refrigeration systems, which is the largest part that drains a lot of energy in relation to the rest of the other parts. Therefore, modern science tends to save energy in spite of the high temperatures in the summer, which negatively affect the performance coefficient of cooling systems and increase energy saving [7][8]. While energy consumption must be reduced and the COP increased without adding significant costs to the systems, and from here work begins to reduce compressor energy saving by reducing the pressure in the air conditioning system, which leads to an increase in the COP in the final result [9][10], and the pressure is reduced by lowering the temperature of the condenser which usually operates on forced convection heat exchange with outside air. The high temperature of the outside environment in summer and noontime causes the air conditioning system to turn off or power exhaustion significantly[11][12]. Hence, when started using the direct evaporative condenser, which uses a quantity of water in the form of a spray to contact the surface of the condenser, which leads to the withdrawal of a quantity of heat that leads to its rapid evaporation due to the large surface area of the water spray, and the shape of the evaporative condenser is a major factor in its efficiency [13]. Also, humidity has a significant impact on COP and energy saving [14] [15]. Thus, reducing the temperatures inside the condenser and thus reducing pressure and obtaining savings in the energy consumed by the compressor. The size of the evaporative condenser is smaller than the size of the air-cooled condenser. The flow rate of the water mass is controlled by temperature and humidity sensors so that there is an economy in the required amount of water, unlike the water-cooled condenser, which drains a larger amount of water[16][17]. The evaporative condenser is a tube and fin heat exchanger, sprinklers, tank, and a small pump.

1-2 Reciprocating refrigeration cycle

The basic parts of simple air conditioning unit are as follows in Figure (1.1):

Compressor: There are many types of compressors used in refrigeration systems. The compressor works in two ways: the first is by coils that run on electric current. While there are several compressors operated by a separate motor and connected to the compressor by a belt. There are many types of compressors using in air conditioning unit that have small capacities like: (reciprocating, rotary, scroll). While the rotary compressor is the most widely used because of its low energy consumption compared to the reciprocating compressor .The compressor generally increases the pressure to the maximum. It works to convert the refrigerant fluid from saturated vapor to superheated vapor. In the compression stage, the fluid has the highest pressure and highest temperature. To the calculations of the compressor, the entropy can be considered constant.

Condenser: is a heat exchanger used to reject the heat gained from the coolant during compression processes to the outside air. The condenser is an important part of the refrigeration cycle. The condenser is the second part after the compressor works. It receives the refrigerant coming from the compressor in the case of super-heated vapor, to be converted at the end of the condenser into a liquid at high pressure. The heat rejection by the condenser is according to the principle of forced convection by a special fan[18]. To simplify the calculations, we assume that the pressures are constant at the inlet and outlet of the condenser. Condenser are usually divided into three types. The first type is the air-cooled condenser, and this type is the most common because of its simple structure, and it does not need a water source.

The air-cooled condenser is characterized by low initial cost, operation and maintenance cost when compared with other types of condensers. It works well when temperatures range between (15-20) degrees Celsius above the ambient air temperature [19]. The second type is the water-cooled condenser, which expels heat to the surrounding water and then is also expelled to the surrounding air as in cooling towers. The water-cooled condenser has a much higher efficiency than air-cooled condensers. The water-cooled condenser requires additional equipment such as pumps and sprinklers as well as a water source, which increases the initial costs of the condenser. Water-cooled condensers require chemicals and continuous maintenance, which leads to increased operational costs. Water-cooled condensers are distinguished by the fact that their construction sites are far from the rest of the parts of the air conditioning system. Water-cooled condensers can be used from systems with capacities ranging from 0.5 to 10,000 TR [20] . The third type of condensate is the evaporative condensate, which is a mixture between the first type and the second type. Which is considered a development for the first type, which is the air-cooled condenser in order to increase its efficiency in rejecting a larger amount of heat through the evaporation of water with the air stream to remove both sensible and latent heat. The evaporative condenser requires a small rate of air flow, unlike the air-cooled condenser. The initial and operational costs of the evaporative condenser can be considered less than the rest of the types because it needs a fan that has a smaller motor and does not require large amounts of water or chemical treatments. Systems that contain an evaporative condenser are characterized by a higher performance factor than their counterparts and have more energy savings[21]. Condenser are shown in Figure (1.2).

Expansion valve: the expansion valve is the third of the basic parts that must be provided for the work of refrigeration systems. There are many types of expansion valves: (capillary tube, electric expansion valve, thermal expansion valve, automatic expansion valve, etc.). Capillary tube expansion valve is commonly used in small capacity and fixed refrigeration systems. The expansion valve works to reduce pressures from the maximum pressures to the minimum pressures. It works to convert the refrigerant fluid from a saturated liquid to a mixture as a result of reducing pressure and temperature. The expansion valve is located between the condenser and the evaporator. To simplify the calculations, assumed that the enthalpy is constant at this point. Expansion valve is shown in Figure (1.1).

Evaporator: The evaporator in small capacities of air conditioning units is a heat exchanger that works the same as a condenser but the process of heat exchange between the room air to be conditioned and the refrigerant fluid. The evaporator is one of the important engineering designs in order to provide comfortable conditions in terms of humidity and temperature. The evaporator works by forced convection of a fan. The evaporator consists of tubes and fins to increase the surface area for heat exchange. The evaporator is manufactured on the basis of low pressure and low temperature. The evaporator works to convert the refrigerant from the mixture state to saturated vapor and travels back to the compressor, so the cycle continues. To simplify the calculations for the evaporator, assumed that the pressures are equal at the inlet and outlet of the evaporator.

1-3 Evaporative condenser

The evaporative condenser is a combination of air-cooled condensers and water-cooled condensers. The evaporative condenser is an improvement of the air-cooled condenser with lower costs and greater economic return for the system[22][23]. Where researchers classified the evaporative condenser as one of the effective solutions to improve the performance of air conditioning units and reduce energy consumption[24][25],as well as allowing the unit to work even with low voltages [26][27]. The performance of the evaporative condenser is affected by relative humidity as well as (wind speed, dew point temp, flow rate of water, and refrigerant flow rate)[28][29]. One of the most important advantages of evaporative cooling is that it is environmentally friendly and does not contain atmospheric pollutants[30][31]. The evaporative condenser is divided into the following three types[32]:

1.3.1 Direct evaporation: In this method, sprinklers are made by pumping a mist of water directly into the condenser coil. Then the water mist evaporates from the surface of the condenser to absorb a large amount of heat[33][34]. The direct evaporative condenser works to reduce the surface temperature of the condenser by a large amount because the specific heat capacity of water is approximately four times greater than the heat capacity of air, and spraying water on the surface of the condenser cleans it of dust on the surface of the condenser [35].

1.3.2 Indirect evaporation: In this method, the air entering the condenser is cooled by a heat exchanger or separated from the condenser. Here the incoming air is either air-cooled by evaporation or mixed with water vapor, making it moist air. This method also helps to increase the performance coefficient and is more economical than the water-cooled condenser. But less than the first method[36]. The performance of an evaporative condenser varies depending on the thickness and type of pad used [37].The indirect evaporative condenser is a rapidly developing technology used in hot and dry areas [38][39] as shown in figure (1-2).

1.3.3 Mixed fumigation: This method is an intermediate state between the first and second methods. Its components are a combination of the two methods and work to increase the COP and energy saving. The evaporative condenser used in simple systems usually consists of tubes and fins, as in air-cooled condensers. But here a water tank, pump, and sprinklers are added [16].

1.4 Energy saving.

Air conditioning systems are considered one of the systems that drain a large rate of energy during the year, especially in the summer season, especially in climates whose temperature reaches more than 40 °C. Hence, studies are still going on to reach the greatest savings in energy consumption without reducing the cooling revenue or reducing the efficiency of the system. A sample was taken consisting of three commercial buildings in China - Hong Kong, and it was concluded that 98% of the annual energy consumption falls on the shoulders of the air conditioning systems [21].

There is growth is in many sectors that drain a large part of the energy, for example (industry, population growth, transportation, and air conditioning are directly connected with the increase in the time spent by occupants inside buildings). The energy consumed by air conditioning and refrigeration in the United States is accounted for 50% of the building's consumption and 20% of the total energy consumption[36].

As for Europe, the increase in the number of air conditioning and refrigeration systems between 1980 and 2002 had a significant impact on energy consumption, which is estimated at about 40.3% of energy consumption in residential and commercial buildings. The total air-conditioned areas in 1980 were 30 million square meters down to 150 million square meters in 2000 [40].

International Energy Agency has increased concerns about the growing population and the increasing demand for energy consumption, where data were collected on energy consumption during the two decades (1984-2004). The increased growth in primary energy was approximately 49% and carbon dioxide emissions by 43% with an annual increase rate of 2% and 1.8%, respectively. The average annual consumption rate is 3.2% in the regions of Southeast Asia, the Middle East, South America, and Africa, which are considered to be the role of a limited economies. While for developed countries, by 2020, the growth rate will be 1.1% [21] .

The increase in global energy consumption between 2001 and 2005 is approximately 58%. Since the main source of energy comes from fossil fuels, which amount to approximately 80%. Since the above results and studies indicate that the most energy consumption comes from air conditioning and refrigeration systems, especially in the summer. It required the protection of the population and the environment from emissions that harm the health of the population and global warming.

1-5 Motivation.

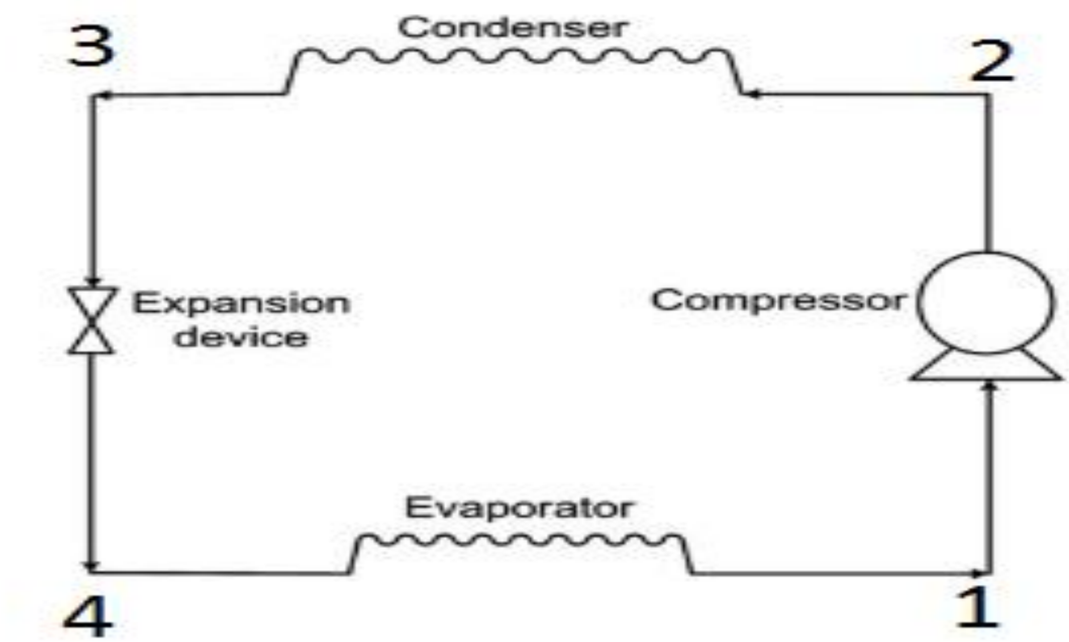
The motive behind this study is to increase (the coefficient of performance) as well as energy saving of HVAC and refrigeration systems.

1- This study is suitable for the regions of the Middle East (Iraq) that suffer from high temperatures of more than 40 °C in summer. In this study.

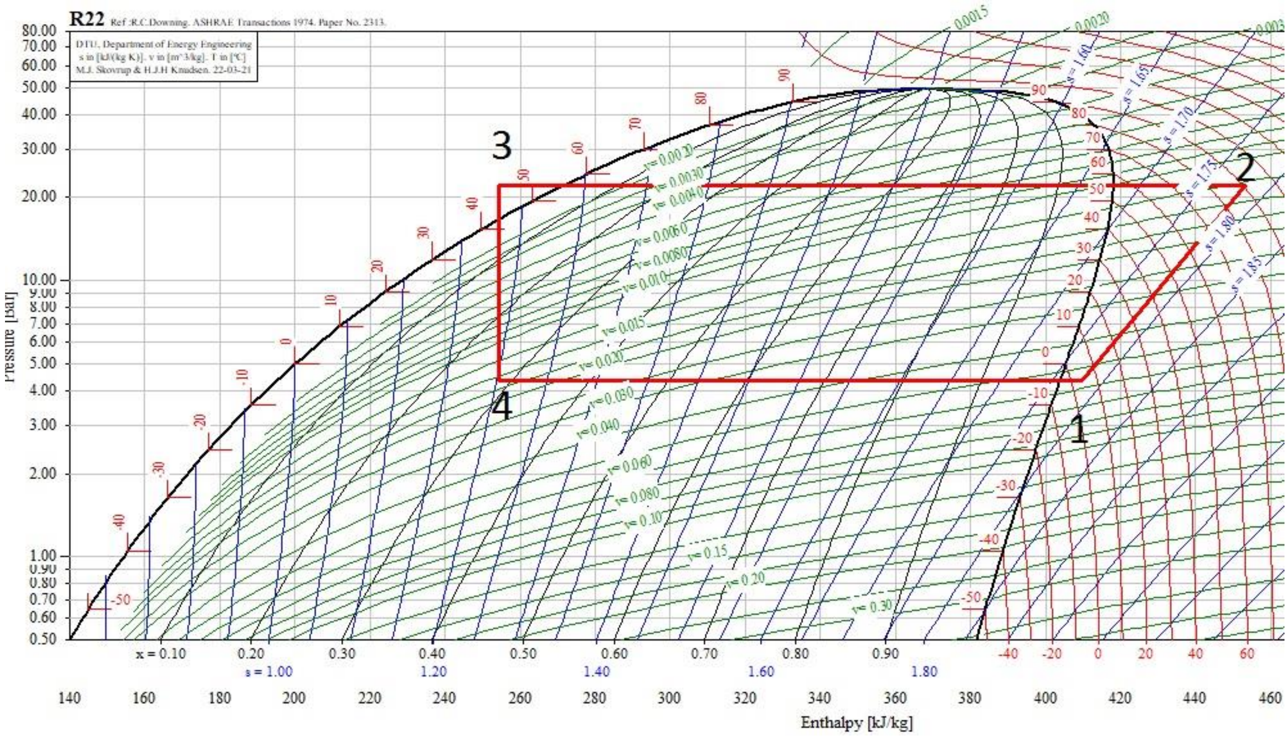
2- Indirect evaporative condenser was used using sprinklers connected to a water pump and tank. Nebulizers moisten the air before it comes into contact with the surface of the condenser. This method increases the rate of heat transfer by a greater amount by removing a greater amount of heat that is felt through the evaporation of water on the surface of the condenser. The amount of heat transfer reduces the temperature on the surface of the container, so the pressure inside the condenser decreases, and as a result, an increase in the performance coefficient and a decrease in the amount of energy saving are obtained.

1-6 Objectives of the study

This study aims to enhance the COP of the air-cooled condenser for the split-type air conditioning unit that works with Freon gas (R22) and has a capacity of (1 refrigeration ton) by using the indirect evaporative condenser was added to the air conditioning unit. The following parameters (dry bulb temperature, wet bulb temperature, humidity, air velocity, pillow thickness, water volumetric flow) were studied, where three-volume flowrate of water (100, 125, 150) liters / h will be used, and three Pad thickness (3, 5, 7) cm and air flowrate will be fixed. The impact of this improvement on energy savings and COP will be studied..



(a) Schematic of reciprocating refrigeration cycle[41].



(b) Reciprocating refrigeration cycle on p-h diagram

Figure (1-1) (a-b) Reciprocating refrigeration cycle [42].

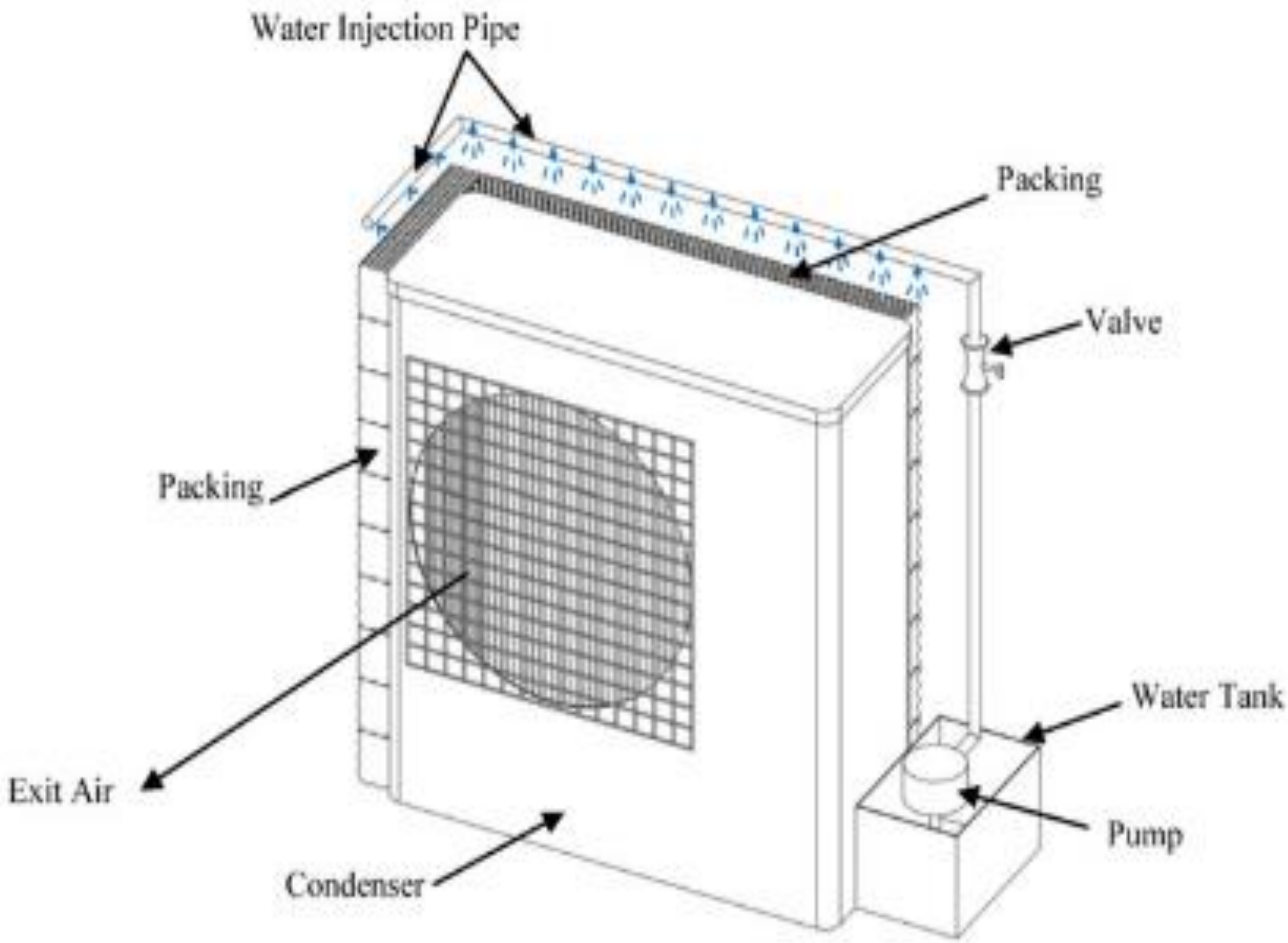


Figure (1-2) Indirect evaporative condenser [43]

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Introduction

In this chapter, the most important previous studies of HVAC units with evaporative condenser will be presented. These studies will also be divided in proportion to the current study, with each section to be clarified. The evaporative condenser and its effect on the rest of the system in terms of energy savings and performance factor will also be shown. Previous reviews show the possibility of using evaporative condensers with HVAC units.

2.2 Experimental studies

Goswami et al. 1993[44] was used an indirect evaporative condenser pad experimentally to study its effect on increasing the performance factor of a 2.5-ton (8.8 kW) refrigeration system. The researcher pumped air & water vapor compressed. The COP of the system was monitored without any addition for a period of four weeks, where the calculations were made at the ambient temperature of 33.3 °C and the air flow rate at the condenser (1.15 m3/s), the extracted readings were recorded and the system COP and the energy seving in this condition were calculated. The experiment was repeated after adjusting the system using the indirect evaporative condenser for the same previous period (four weeks) and for the same previous conditions, and the results were recorded and compared. An increase in the COP of up to 20% was achieved by using an evaporative condenser more than the air-cooled condenser.

The amortization of the additional costs of retrofitting the cooling system was also calculated in less than two years of energy savings resulting from the improvement. As shown in figure (2-1).

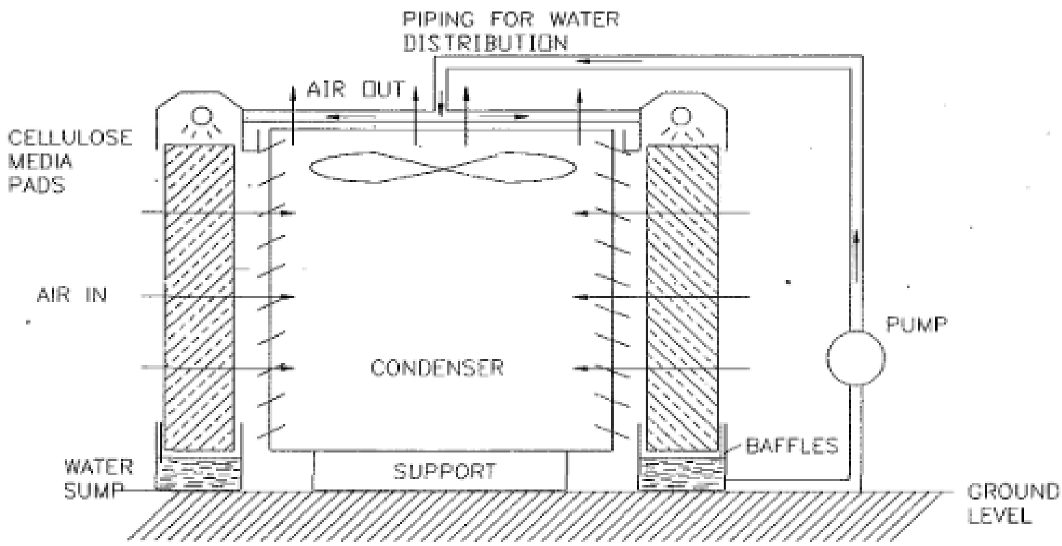


figure (2-1) Goswami et al. test rig

Hajidavallo et.al 2007 [45] The researcher experimentally added the development of the air-cooled condenser for a window-type air conditioner operating in the Middle East regions with a temperature higher than 50 degrees Celsius or in vertical construction, which leads to the rise of hot air from the first floors to the upper floors, which leads to a significant increase in temperatures. The researcher used the indirect evaporative condenser by placing two air cushions on both sides of the window air conditioner. It is concluded that COP decreases by 40% at higher temperatures, and the coefficient of performance decreases by about 2-4% when each °C increases the temperature of the capacitor. After adding the indirect evaporative cooler, an energy saving of 15% and an increase in the cooling capacity of about 33%, and the COP increased by about 55%, was obtained. As shown in figure (2-2).

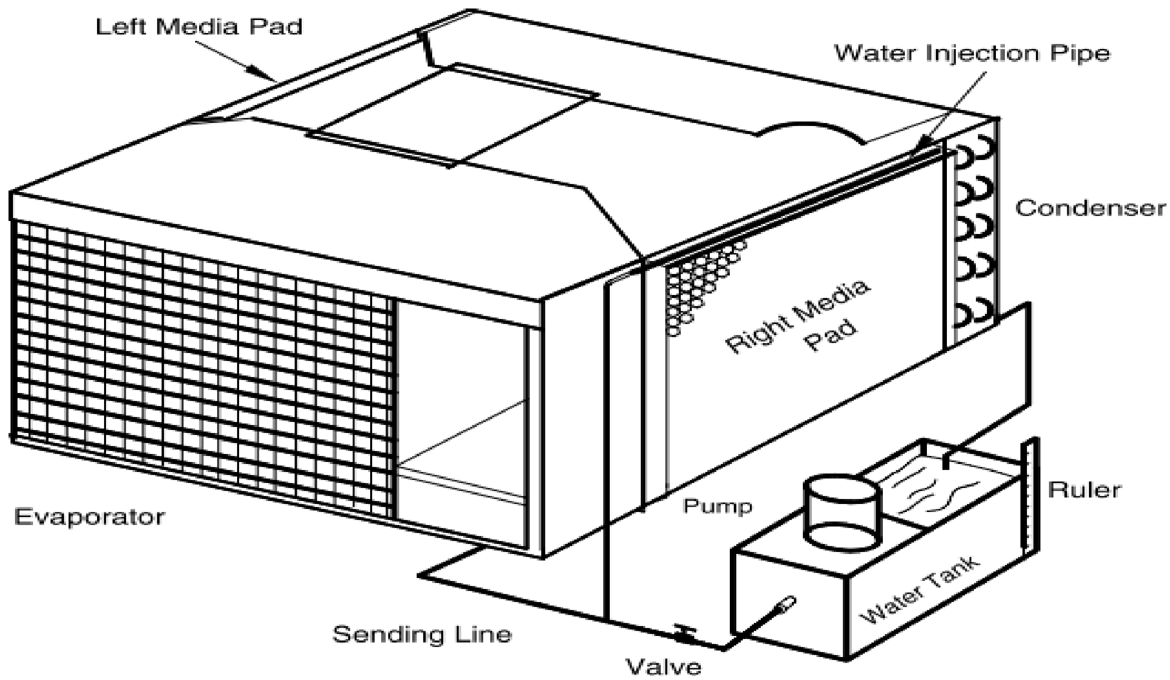


figure (2-2) Hajidavallo et.al test rig

Tianwei et al.2014 [46] made practical experiments on a refrigeration device with a capacity of 2.5 kilowatts. It works on a refrigerating fluid of the type R410a Freon gas. Several parameters such as (dry bulb temperature, air velocity, and water flow rate) were studied. When comparing the use of the air-cooled condenser with the evaporative condenser at dry temperatures (23.8, 27.8, 33.1, 38.9, 44.9) °C, the experiment proved that the temperature was increased by sensible heat transfer with constant relative humidity. When using the evaporative condenser, there was a clear decrease in temperature compared to a rise in relative humidity due to the evaporation of water caused by the transfer of latent heat. The use of the evaporative condenser decreasing the saturation temperature from (2.4 to 6.6) °C , which led to an increase in mass flow inside the evaporator, which increased the COP from 6.1% to 18%, and reduced compressor works up to 14.3%, saving energy. The best results of the system were at a dry temperature of 33.1 °C.

Eidan et al. 2017 [27] Studied indirect evaporative cooling was on a cooling device at high temperatures up to 55°C (Middle East regions - Iraq). The effect of the direct evaporative condenser in this study was calculated on (COP, energy-saving, cooling capacity, and automatic shutdown of the system), which will be calculated through the following parameters (dry temperature, air velocity, relative humidity). When comparing the system with the air-cooled condenser and the evaporative condenser when choosing different temperatures ranging between (45-55) °C and relative humidity of 10%. The average velocities were chosen between slow, medium, and fast (1-2-3) m/s, respectively. It has been scientifically proven that the efficiency of the evaporative condenser is directly proportional to the speed. The pressure also decreases with a decrease in speed as well. As a result, the speed can affect the COP and energy saving significantly. The results were positive on all of the above variables as follows: The cooling capacity increased approximately from 5% to 7.5%, also the energy saved between (22.45% - 33.96%). The power consumption was reduced between 0.12 and 0.16. Ampere and the compressor continue to run even when the voltage drops to 185 volts.

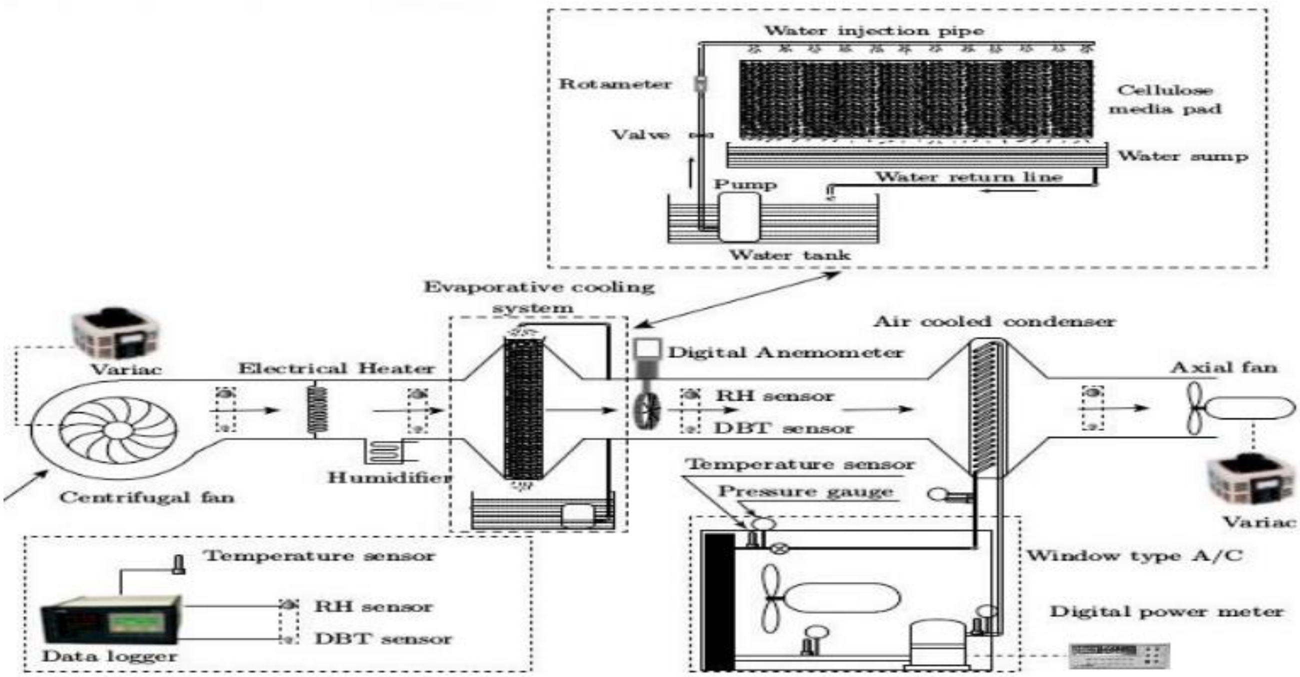


figure (2-2) Eidan et al. test rig

Mohammed et al. 2017 [43]further improved the split-type air conditioning system by adding an evaporative condenser as well as a Hybrid PID differential control unit. The use of the evaporative condenser with the control unit was studied through the parameters (dry air degree, air velocity). The speed is controlled according to the sensors of the dry temperatures of the surroundings, which work to equip the controller with the required signal in order for the controller to work after that by controlling the fan speed after the alternating current system fan was replaced by a DC fan. Experiments were carried out at temperatures (of 35, 40, and 57) °C. The controller works to manipulate the fan speed incrementally when the temperature increases from 35 °C to 40 °C. When the dry bulb temperature exceeds 40 °C, the controller works to prepare the water mist. It also reduces the speed when the dry temperature drops below 35 C, which leads to quieter operation and energy saving. Results demonstrated that COP increased from 17.14% to 109.1% at temperatures from 40 °C to 57 °C, while the increase in energy savings was from 20.67% and 46.63% at temperatures from 45 °C to 57 °C compared to the cooling system before optimization.

Hussain. 2019 [47]calculate the change in the COP of a cooling system operating with a refrigerating fluid of the type R22 Freon gas according to the use of two types of condensers. The results were based on changing the airflow velocity as follows: (4.5, 6.0, and 7.5 m/s) with the temperature fixed at 29°C. The results of calculating the COP of the air-cooled condenser and evaporative condenser were compared. It has been practically proven that the COP of the system increases with increasing airflow for both air-cooled and evaporative condensers, but the latter has a much higher COP than the first air-cooled. A higher COP was obtained when using an airflow of 7.5 m/s compared to the other speeds, which were 3.19 and 3.51 for the air-cooled condenser and the evaporative condenser, respectively.

Mohamad et al. 2020 [34] the use of a direct evaporative condenser was studied on a car air conditioning system of the Proton Wera type, operating with a refrigerating fluid of the Freon gas type R134a. The study was carried out according to the parameters (temperature, volumetric flow rate of water) with stability (compressor speed 1550 rpm, condensed water temperature, air inlet temperature). The following temperature was taken when calculating (28, 32, and 36) C. The volumetric water flow rate was (0, 140, 340) ml/min. The study proved that the performance coefficient increases directly with the volumetric flow rate of condensing water from 0 to 140 ml/min. The highest COP was obtained at 32 °C and at condensed water of 140 ml/min which was 3.66. The lowest COP drop was 15.9% at the evaporator air inlet temperature of 36 °C.

Naveenprabhu and Suresh. 2020 [29]experience an indirect evaporative condenser with and without a cellulose cooling pad. The test was conducted in two regions with different climates. The first region has a cool and humid climate. While the second region has a hot climate and lower humidity. Several parameters (dry bulb temperature of ambient air and outlet of water spray, air velocity, relative humidity, cooling rate, spray water evaporation rate, volumetric heat, and mass transfer coefficients) were studied. The dry bulb temperature, as well as the relative humidity between the outside air and the outlet temperature of the sprinklers, were compared, and the maximum deviation was 15% between the experimental and simulation results. The parameters (cooling rate, spray water evaporation rate, volumetric heat, mass transfer coefficients) were extracted to calculate the COP. The COP improvement was obtained by using a cellulose cooling pad, the air velocity also had an effect on the cooling and evaporation rate, the dry temperature decreased from (3-5) °C and continued to decrease as the air velocity was lower. The researchers also experimentally obtained the Nuselt and Sherwood number, which is an important component of the calculations of the COP of an evaporative condenser.

Levi et al. 2021 [38]the use of the evaporative condenser was tested on a domestic refrigerator with a capacity of 165 liters, operating with refrigerating fluid of the type Garonne R134a gas. The parameters (COP, energy-saving, cooling effect) were studied and compared between the domestic refrigerator with the air-cooled condenser and after using the evaporative condenser. It has been shown that the COP of a domestic refrigerator with the evaporative condenser is 4.61 and without the evaporative condenser is 3.8. The energy saving of the compressor with the evaporative condenser was 9.7% lower than the energy saving of the normal condenser. Finally, the cooling effect with the evaporative condenser was 5% more than that of the normal condenser.

2.3 Theoretical and experimental studies

Nasr and Hassan . 2009 [48] the researchers added an improvement to the condenser of a home refrigerator by wrapping the tubes in a cloth dampened with capillary tubes attached to a water basin. The effect of the following factors (ambient air temperature, relative humidity, air velocity) on energy-saving and COP was studied. The results were that the condenser temperature decreased significantly with increasing air velocity and increased by increasing the evaporator temperature by 0.45°C when the air velocity was 2.5m/s, the ambient temperature was 29°C and the relative humidity was 37.5%. At an air speed of 1.1 m/s. Also, with an ambient temperature of 31 °C and relative humidity of 47.1%, the increase in temperature of the condenser is about 0.88 °C. On the contrary, the temperature of the evaporative condenser can be less than 20 °C compared to the temperature of the air-cooled at a speed of 3 m/s. It has also been shown that the evaporative condenser's heat expulsion capacity is about 13 times greater than that of the air-cooled condenser. The highest COP of 3.55 and the lowest operating capacity of the compressor was 30.14 kg/kg in the first case. The theoretical model also showed that the evaporative condenser can operate at a condensing temperature of 20 °C lower than the air-cooled condenser.

Minh and Sato. 2013 [49] replaced the air-cooled condenser with an evaporative condenser for cooling systems that face problems in the COP or their high energy consumption in summer due to high temperatures. The effect of the evaporative condenser on the outside temperature, the temperature of the compressor, as well as the energy transmitted to the air, were studied. The researcher aspires to reduce the temperatures and provide a suitable atmosphere for the outdoor unit of the split air conditioner. The practical results were taken every minute and recorded, and the energy saving and COP were calculated for each hour. The effect of the ambient temperature is great on the temperature of the condenser, for example, when the ambient temperature is 35 °C. It can lead to raising the temperature of the condenser to 45 degrees Celsius, meaning that the temperature of the condenser is higher than the ambient temperature at a rate ranging between (5-10) °C for the air-cooled condenser, while the temperature is less than 5 °C for the evaporative condenser, which is expected to save energy saving to 30%.

Islam et al. 2015 [50] have experimentally and numerically studied the effect of the evaporative condenser on the R134a Freon-type refrigerant air conditioning system. The study was conducted on the basis of calculating the change between the variables (dehydration temperature, pressure) between the inlet and outlet of the condenser. The study was conducted at two degrees of dry temperature (30, 35) °C and 2% of the corresponding relative humidity (42, 33)%, respectively. The results were taken practically and numerically for the refrigeration device, where the practical results were to increase the COP by 28% and the compressor work of the evaporative-cooled air conditioning unit over its air-cooled counterpart. The error rate between experimental and simulation results is

7%. It is also possible to increase the COP of systems running with R410 Freon coolant, that is because the latter operates at much higher pressures than Freon R134a type coolant.

Harby and Al-Amri .2019 [51] the researchers studied the indirect evaporative condenser (corrugated cellulose pad) in a split-type air conditioning system. The study was conducted in several regions in Egypt. The parameters (ambient air temperature, relative humidity, ambient air velocity) were studied. The test conditions were at a dry temperature ranging from 30.2 - 50.3 °C and the relative humidity was from 26.3% to 45.4%. The velocity of the surrounding air is between 0.5 to 0.6 m/s. The best results were obtained at a thickness of 100 mm for the cellulose pad, where the COP in cold weather was 29% and in hot climates was obtained 53%. While greater energy saving were obtained ranging from 15 to 22%, which is equivalent to $ 21.6 per year. While the cost of water used was only $1.82 per year. The costs of system improvements can also be covered in three years.

Han et al . 2020 [28] prototyped a new type of evaporative condenser with water-cooled condensing and used it in the 8 kW air conditioning system installed in the data center. The parameters (ambient air temperature, condensing temperature) were studied. A reduction in energy saving of the system by 8.93% compared to the HVAC system was obtained before adding the optimization. The COP was increased by 9.82% at constant cooling capacity despite the lower efficiency of the evaporative condenser compared to the water-cooled condenser.

Suresh et al. 2020 [52] in this study, the researchers have developed a condenser heat exchanger of a type (fin and tube), which is usually air-cooled. The COP of the improved condenser, represented by the evaporative condenser, is calculated due to the lack of water sources in some areas, which prevents the use of the water-cooled condenser. The parameters (heat transfer rate and outlet temperatures of hot water and air) were studied. The experiment was carried out according to a water flow rate ranging from (150 to 450) liters / h. The airflow was 300 CFM. An increase in performance coefficient ranging from (40% to 60%) was obtained. In addition when using the new condenser (evaporative condenser),this leads to significant savings in compressor energy saving.

Yang et al. 2020 [53]they study the effect of the direct evaporative condenser applied to the air-cooled chiller system in the temperate monsoon climate area of Tianjin in summer. The control of water flow rate, angles, and positions of sprinklers, the dry temperature of ambient air, as well as relative humidity ware studied. The COP of the evaporative condenser is 4%-8% higher than that of the air-cooled condenser. The effect of sprinkler locations had a direct impact on the COP, so the results of vertical spraying were 0.28-1.94 higher than horizontal spraying. And the COP increases with the increase in the ambient temperature. The COP when it was 25 °C was approximately 2%, and when the ambient temperature was 40 °C, it increased from 6% to about 9%. Energy saving were obtained by 2.37% to 13.53%, higher than the system before the improvement.

Han et al. 2021 [12]the researchers studied experimentally and numerically the effect of the evaporative condenser on the air conditioning system in four regions with different climates. The parameters (evaporation temperature, condensation temperature, system cooling capacity, performance factor) were studied. The use of evaporative condenser and water-cooled condenser had higher COP and heat transfer coefficients in all test areas. When comparing the practically extracted results with the simulation programs, the deviation rate was 10%. The COP increases and the energy consumption decreases as the climate has lower temperatures.

Behnam et al. 2021 [54] the researchers studied experimentally and numerically manufactured and tested evaporative condenser performance and heat transfer amounts under different conditions. The parameters (dry and wet bulb temperatures, water temperature, condenser saturation temperature, coolant flow rate, air flow rate) were studied and compared practically and theoretically using several simulation programs. The heat transfer rate was calculated. For the ANNMLP model in the 339 test samples, the deviation was ±8%. When using the SVR model for the same set of samples, it is less accurate than the first model, but it was better to predict the heat transfer rate with a number of samples ranging between (50-100) test samples. Also, it is not recommended to use the DT model to predict the performance of the evaporative condenser.

2-3 The Scope of present study

The aim of this study is to identify the weaknesses that were previously studied in the literature through certain parameters as well as to increase (Refrigerant effect, the coefficient of performance, and energy saving) of air conditioners and cooling systems at higher rates, which were not previously reached by providing an improvement in the performance of the traditional condenser for the air-cooled air-conditioning device to suit external conditions throughout the year.

Table (2-1) Summary of literatures

Researcher name	Year	Ref.	Evaporative condenser type	Results summary
Goswami et al .	1993	[44]	indirect	An increase in the performance factor and energy savings of up to 20% was achieved.
Hajidavallo	2007	[45]	indirect	Energy saving of 15%, and the performance factor increased by about 55%.
Tianwei et al.	2014	[46]	indirect	Which increased the performance factor from 6.1% to 18%, and reduced compressor work up to 14.3% saving energy.
Eidan et al.	2018	[27]	indirect	Cooling capacity increased approximately from 5% to 7.5%, and energy saved between (22.45% - 33.96%).
Naveenprabhu and Suresh .	2020	[29]	indirect	The performance coefficient improvement was obtained by using a cellulose cooling pad, the air velocity also had an effect on the cooling and evaporation rate, the dry temperature decreased from (3-5) degrees Celsius and continued to decrease as the air velocity was lower

Chapter Three

Theoretical Analysis

Theoretical Analysis

3.1 Introduction

This chapter aims to show the theoretical part of the current study. It includes the most important arithmetic equations and their derivation, with a statement of the hypotheses and determinants on which this study is based, in addition to supporting the practical side through the use of theoretical programs as explained in the parts below.

3.2 Theoretical part

3-2-1 Compressor work

Compressor work is calculated using two mathematical equations. The first is by calculating the electric current, voltage, and electrical quality coefficient, which is constant in most cases.

Or by the difference in the enthalpy of the points before and after the compressor multiplied by the mass flow of the fluid (m) **:** [55]**,**[12]**,**[56]

$$W = \dot{m}\,(h_2 - h_1) = I * V * \cos\theta \qquad (3\text{-}1)$$

From equation

$$Qc = \dot{m}\,cp\,(T_2 - T_3) = \dot{m}\,(h_2 - h_3) \qquad (3\text{-}2)$$

$$Qe = \dot{m}\,cp(T_1 - T_4) = \dot{m}\,(h_1 - h_4) \qquad (3\text{-}3)$$

$$W = \dot{m}\,(h_2 - h_3) - \dot{m}\,((h_1 - h_3) \qquad (3\text{-}4)$$

C_p = Specific Heat

h = Specific Enthalpy

$\dot{m}$ = mass flowrate [kg/s]

Cosθ=0.85

3-2-2 Refrigerant effect

The refrigeration effect (RE) is the basic function for calculating the coefficient of performance for the unit. The refrigeration effect or the so called evaporator energy (Qe) can be calculated through the difference in the enthalpy of the points before and after the evaporator multiplied by the mass flow of the fluid as shown in the equation below: [56][55]

$$RE = \dot{m}\, C_p\, (T_1 - T_4) = \dot{m}\, (h_1 - h_4) \qquad (3\text{-}5)$$

$$Qe = \dot{m}\, C_p\, (T_1 - T_4) = \dot{m}\, (h_1 - h_4) \qquad (3\text{-}6)$$

3-2-3 Mass flow rate (m)

The mass flow rate of refrigerant (m) is an important function that is included in the calculations (Wc ,RE, Qc) and as in the equations below: [56][55]

$$\dot{\boldsymbol{m}} = RE / (h_1 - h_4) \qquad (3\text{-}7)$$

Use equation (3-7) to calculate $\dot{\boldsymbol{m}}$ from refrigerant effect.

$$\dot{\boldsymbol{m}} \frac{\boldsymbol{W_c}}{(h_2 - h_1)} \qquad (3\text{-}8)$$

Use equation (3-8) to calculate $\dot{\boldsymbol{m}}$ from compressor work.

3-2-4 Condenser capacity:

The energy of the condenser can be calculated by the difference in the enthalpy of the points before and after the condenser multiplied by the mass flow of the fluid as below: [43]

$$Qc = m^{\cdot}\, C_p\, (T_2\text{-}T_3) = m^{\cdot}\, (h_2\text{-}h_3) \qquad (3\text{-}9)$$

3.2.5 Coefficient of performance (COP)

The coefficient of performance (COP) is one of the most important results that prove the efficiency of any air conditioning unit. The performance factor depends on two parameters, which are the refrigeration effect and compressor energy, as in the equation below: **ref**[12]**,**[8]

$$\text{Cop} = \frac{Q_e}{W_c} \qquad (3\text{-}10)$$

By equations:

W=m(h2-h1) (3-11)

Q= m (h1-h4) (3-12)

$$\text{COP} = m^{\cdot}\, (h_1\text{-}h_4) \,/\, m^{\cdot}\, (h_2\text{-}h_1) \qquad (3\text{-}13)$$

3-3 Assumption.

Assumptions can be divided into two parts, which are as follows:

3-3-1 Constant properties.

1- Assuming the compressor's working procedure as an isotropic procedure.

2- The procedure inside the condenser is the isobaric procedure (pc=c).

3- The procedure inside the expansion valve is the adiabatic procedure (h=c).

4- The procedure inside the evaporator is isobaric procedure (pe = c).

5- Imposing an electricity quality factor (0.85).

3-3-2 Steady state condition.

1- The compressor's work does not contain losses (efficiency 100%).

2- Incompressible flow (air).

3- Neglecting the pressure drop during flow.

4- Ignoring gravity.

3-4 Engineering equation solving program.

Engineering Equation Solver **(**EES): It is an engineering program that focuses on solving nonlinear algebraic equations, as well as differential and integral equations, in particular for refrigeration systems. Because the program allows us to acquire linear and nonlinear regressions as well as convert different units, the findings extracted using this program are more dependable. The EES program includes thermodynamic and transformational databases that can be used to solve differential equations in a variety of methods. This program is useful for mechanical engineers because it provides a variety of features in the subject of thermodynamics and heat transport difficulties. Solver saves geometric equations and eliminates the need to solve problems by hand.

The EES program is characterized by many features that facilitate the extraction of results, the most important of which are:

1- High speed in arithmetic operations.

2- High accuracy in solving thermodynamic problems.

3- Convert units and automatically check the stability of arithmetic units.

4- Ability to improve univariate and multivariate.

5- Professional 2D and 3D drawing with automatic updates.

6- Output, PDF and print.

7- Graphical input and output parameters.

8- Ability to connect with Fortran, C, Python, Excel and MATLAB .

3-4-1 Equations Window.

This window includes the necessary equations and variables to extract the required results such as (COP, Wc)

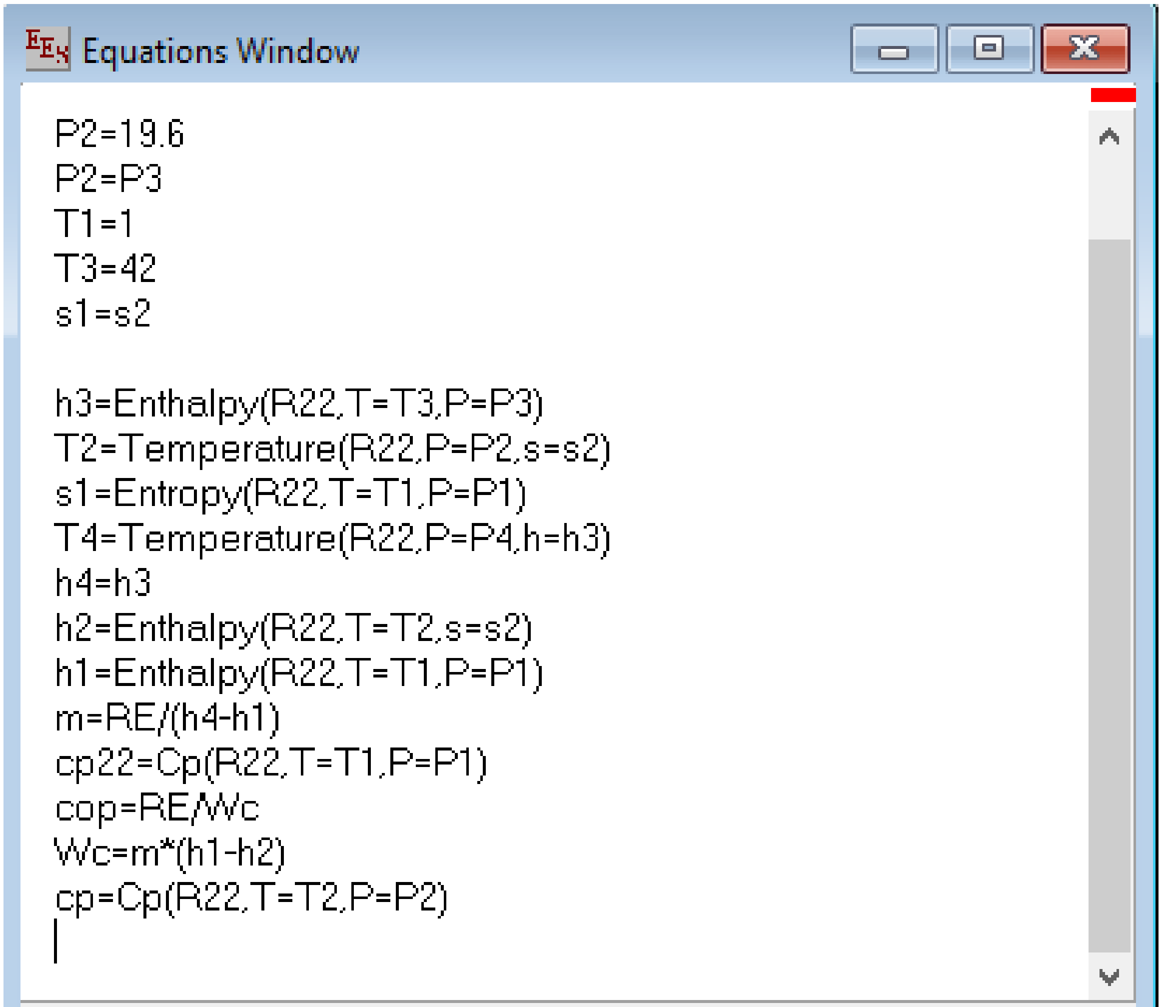


Figure (3-2) Equations Window

3-4-2 Solution Window.

This window includes the results that were calculated by the program through the equations and variables that were entered in the equations window

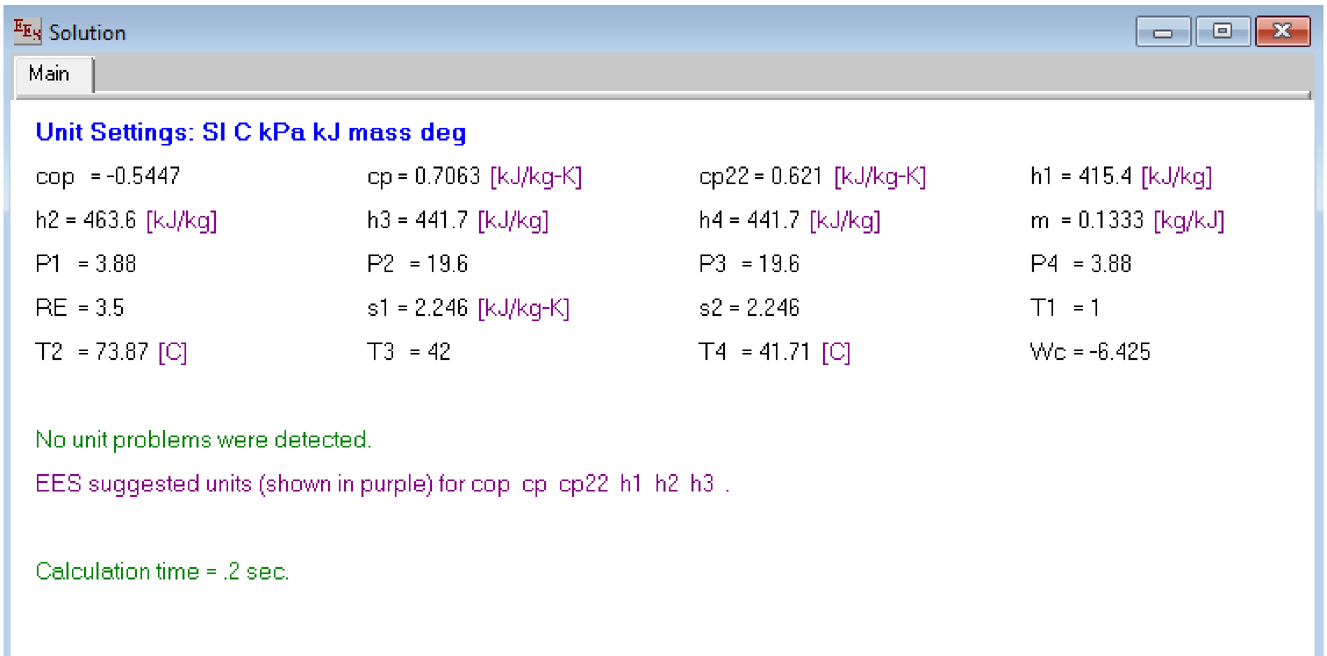


Figure (3-3) Solution Window

3-4-3 Diagram window.

This window includes Charts, pictures, and Tables that can be used to clarify the situation under study and calculation to facilitate the inclusion of equations and variables needed for the solution.

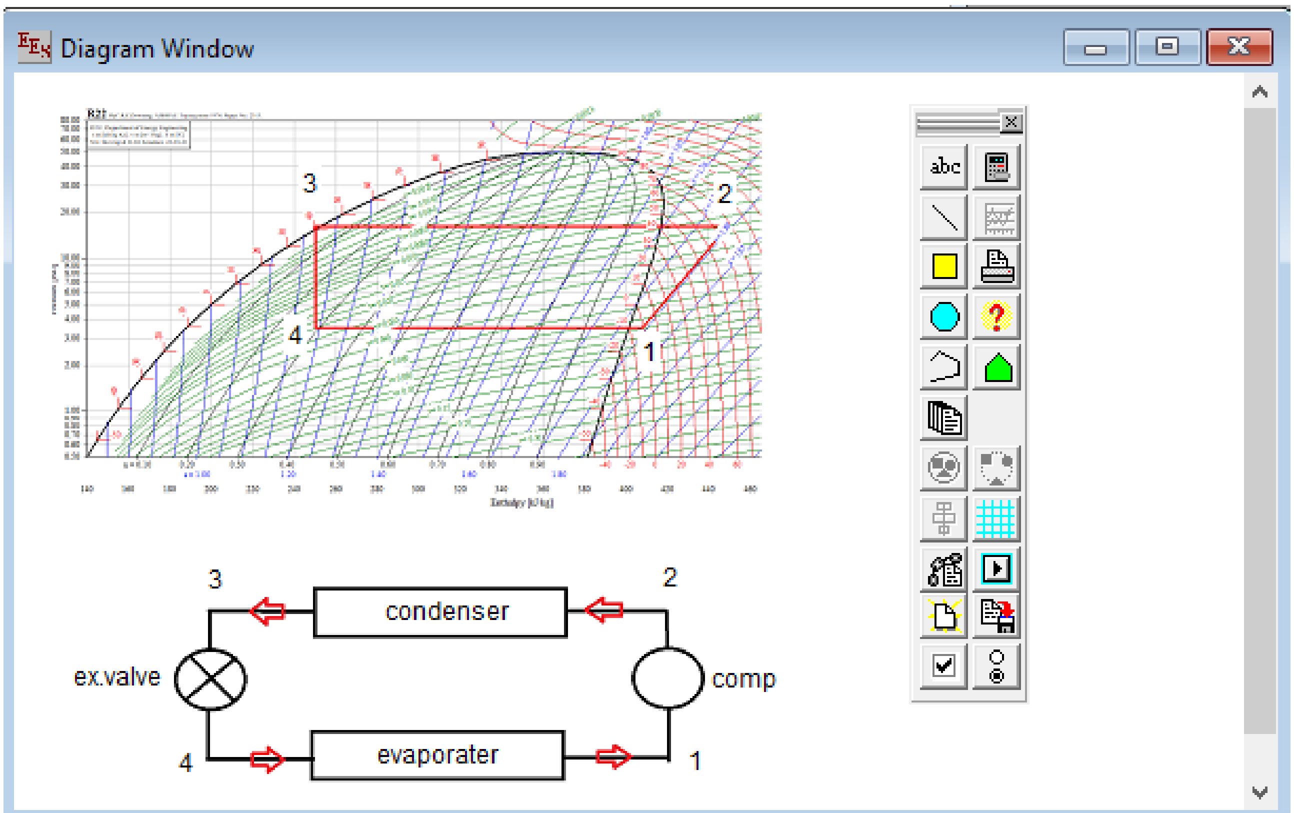
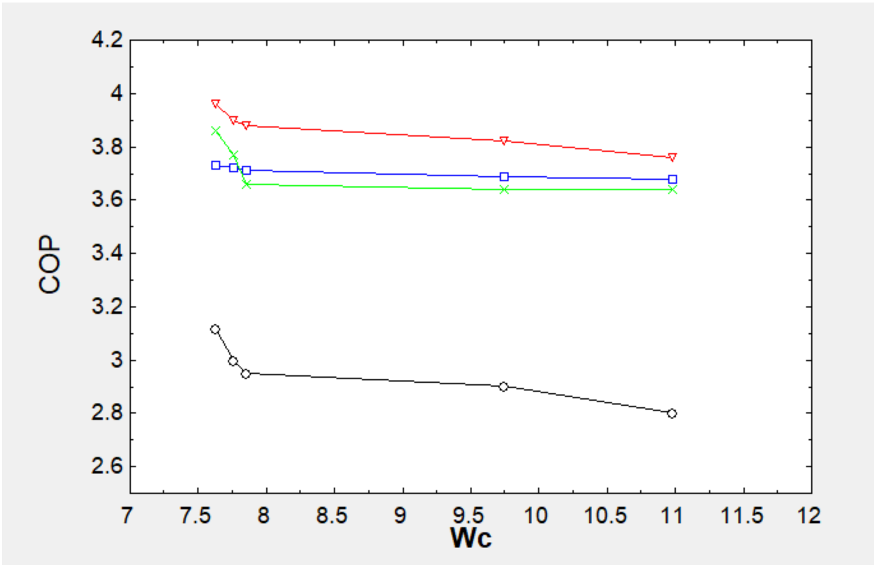


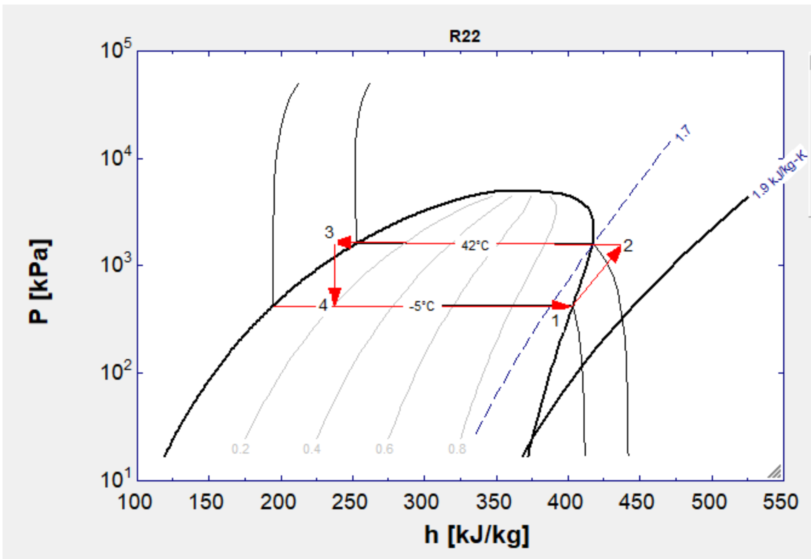
Figure (3-4) Diagram window of refrigeration

3-4-4 Plot windows.

This window includes the diagrams obtained from the program, which are used for the purposes of illustration or comparison, or represent the work of the session on (p-h, T-S) diagrams, etc.



(a) Relation between COP & Wc



(b) p-h diagram

Figure (3-5) (a & b) Plot window

3-4-5 The purpose of using (EES).

EES facilitates some of the procedures shown as below:

1- It facilitates mathematical calculations by providing the user with some equations and physical properties of the fluid used.
2- Results can be compared directly by changing one parameter and showing its effect on the rest of the variables and placing them in a table
3- It is easy to draw any system in the diagram window to facilitate placing fixed and variable transactions in their correct places by numbering the fixed points.
4- It describe the behavior of the unit on a (p-h) chart or on a graph.

3-5 Cool Pack Program.

In addition, the professional Cool Pack program was used to draw cycles on a p-h diagram to extract the enthalpy before and after any of the basic parts of the unit. The program also calculates the COP for each cycle. The results were compared with the arithmetic results, and the error rate did not exceed 2%. We can also compare more than one unit on the same chart, for example in Figure (3-6) below :

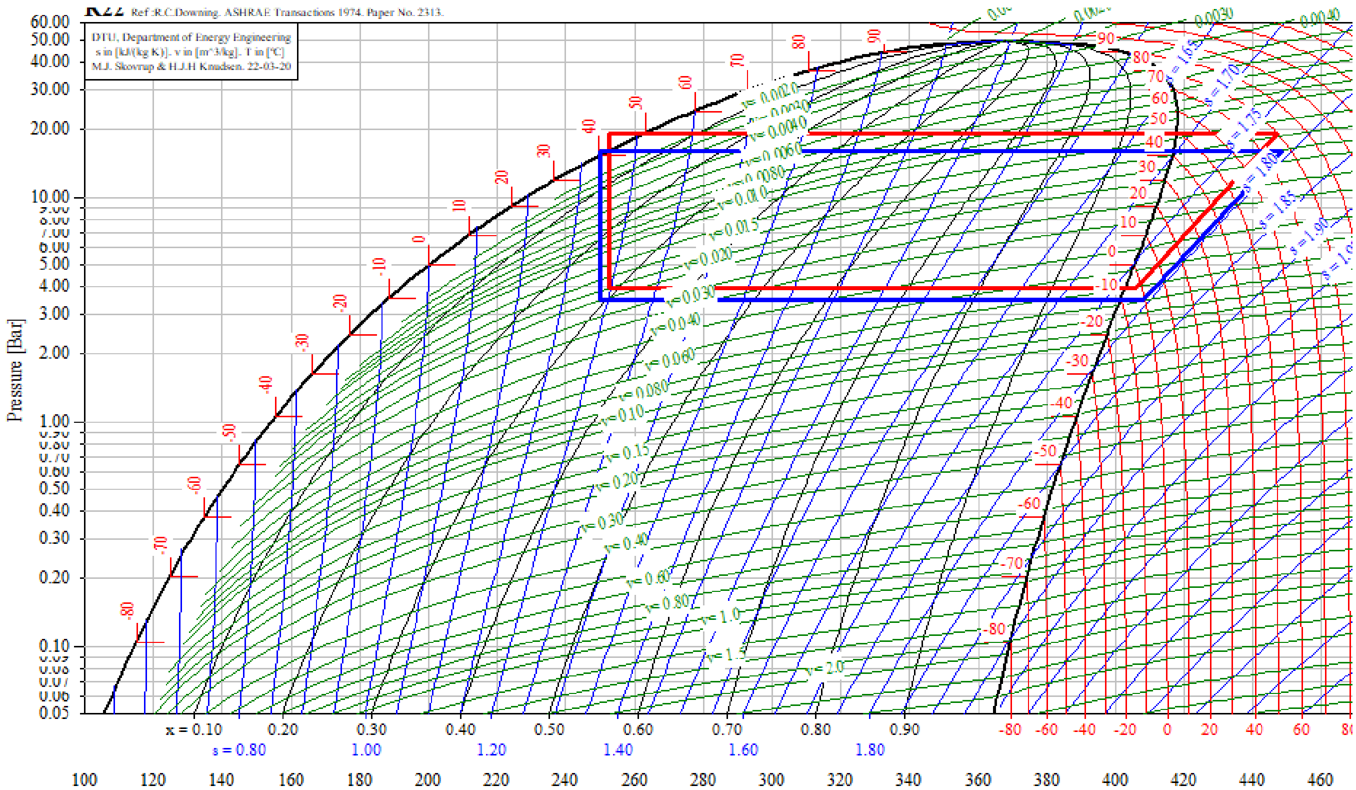
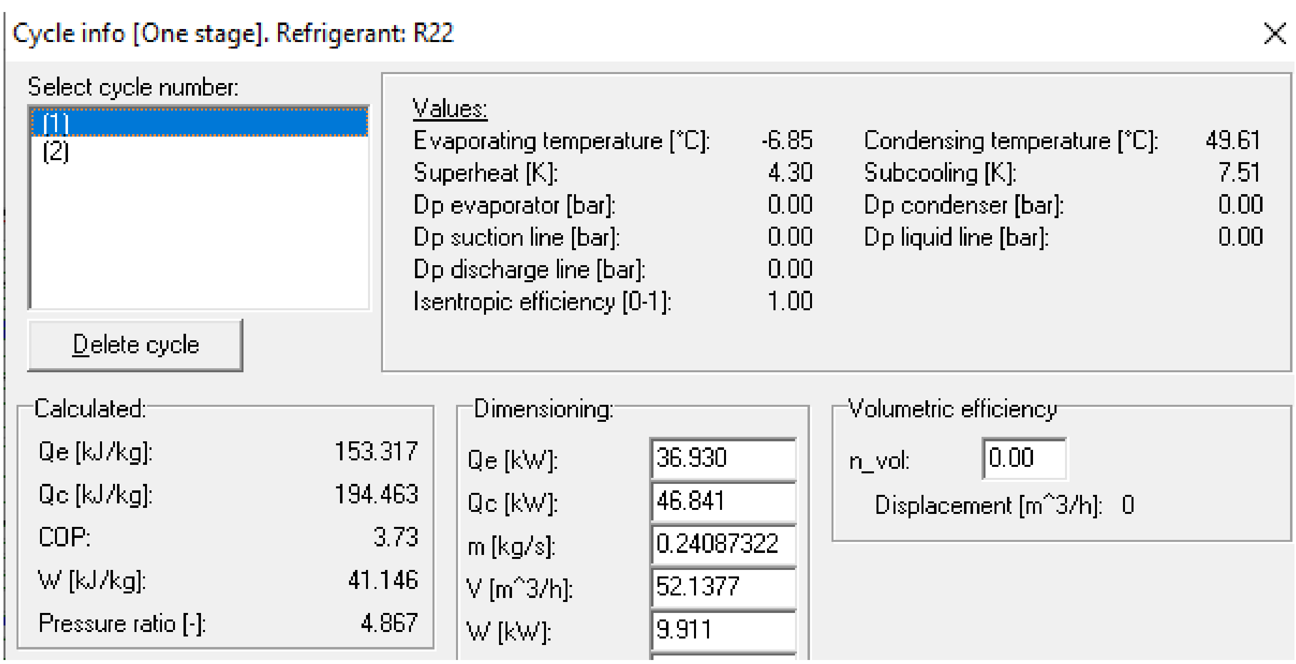
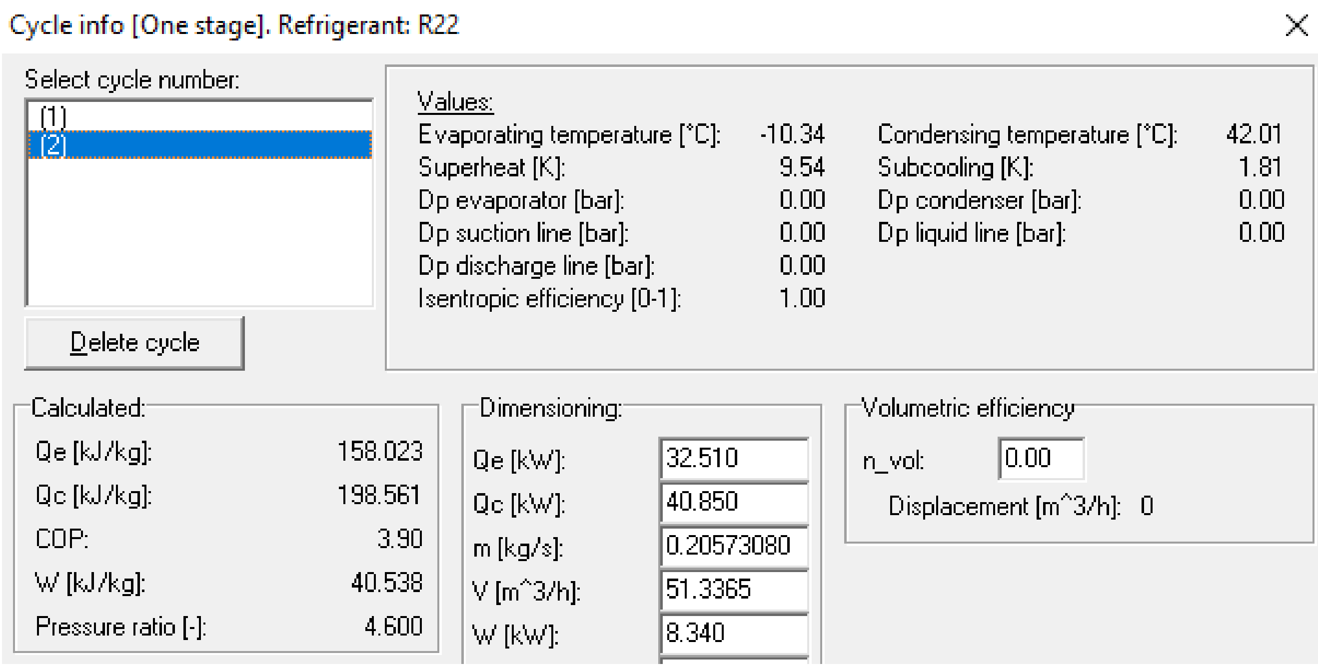


Figure (3-6) Two unit on p-h diagram in same time



(a) result for reference unit



(b) result for modified unit

Figure (3-7) (a) result for reference unit , (b) result for modified unit

Chapter Four

Experimental Work

Chapter Four

Experimental Work

4.1 Introduction

The purpose of this chapter is to present the details of the test device that was made, the measuring devices, as well as how the test performed. The factors that affect the COP and energy saving in the summer season for regions with a temperature of more than 45 °C have been studied. The practical study is conducted in the province of Baghdad.

4-2 Experimental test rig:

The capacity of rigid is (1-ton air conditioner split unit, R22 Freon refrigerant, rated Volt 220V-240V, power input 1090W, current input 5A). The outdoor of air conditioner unit is placed inside a duct of dimensions (50 * 60) cm and a long of 1 meter shown in Figure (4-1). The air duct is used to simulate the outdoor conditions in the summer of Baghdad by using a range of electric heaters rated at 15,000 Watts. The temperatures were controlled through the use of a voltage regulator (Variac). The temperatures of dry bulb and wet bulb were measured by (10 thermocouples) type (k) ,which is fixed at many location and read by a digital readout device. Air velocity is also measured with a digital air flow meter. A water flow meter was also used to measure the amounts of water used to moisten the filling. A digital pressure differential is used to measure the pressure difference due to the use of the filling. The quantities of water used in wetting the stuffing were controlled to be (100, 125, 150) liters / h. We also used three pads of different thicknesses (3, 5 and 7) cm.

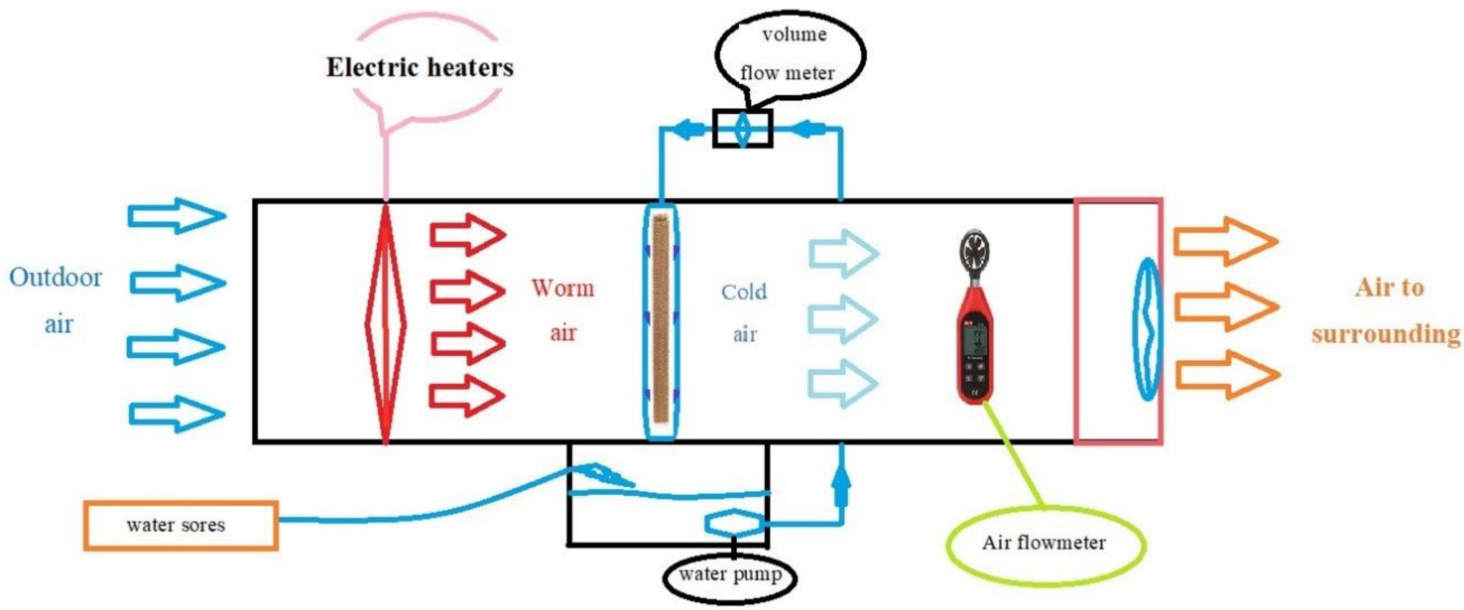
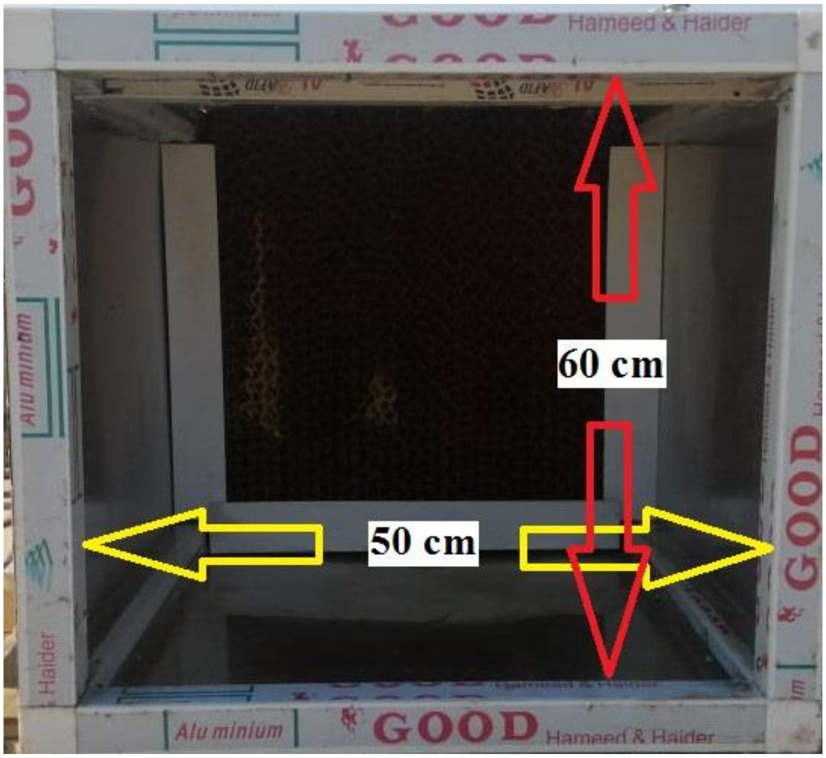


Figure (4-1) Duct with boundary condition

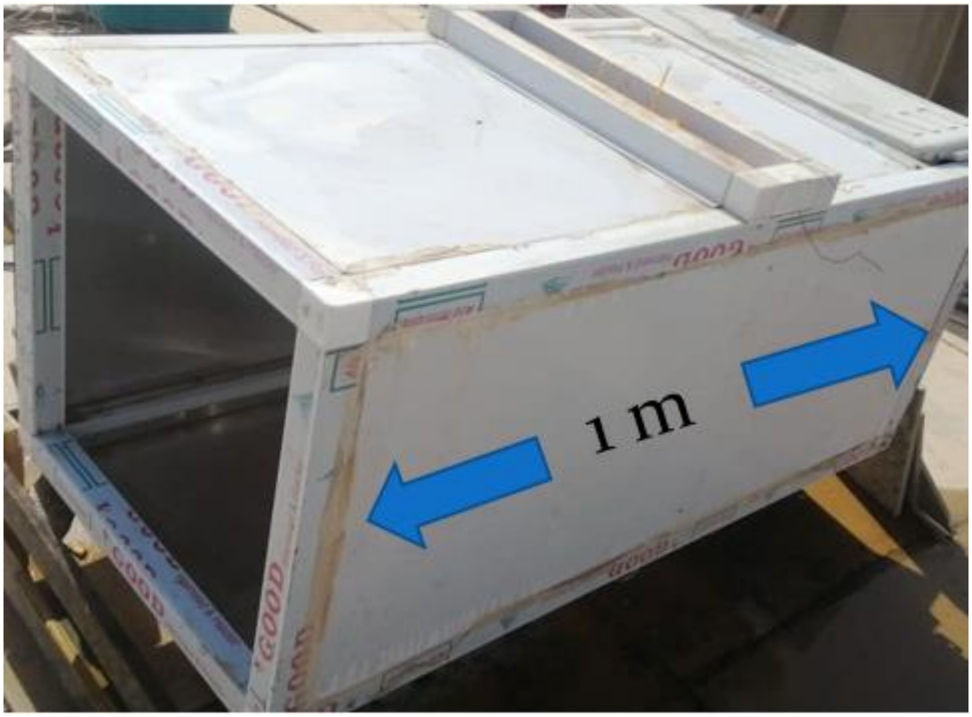
4-3 Components of experiment device:

4-3-1 Duct.

The duct is made of aluminum, with dimensions (50 * 60) cm and a depth of 1 m. The external unit of the air conditioning unit is installed inside the duct to control the speed and temperatures entering the condenser coil. The condenser was placed at the end of the duct, 1 m away from the air intake hole. Each of the other parts was installed inside the duct, which consists of (electrical heaters, stuffing, thermocouples, air velocity measuring device). While water sprinklers were placed in the form of a duct on the upper wall of the duct to moisten the filling only, and a duct was also placed at the bottom of the duct to collect the return water from the pad. Also, a pressure drop gauge was placed through two holes on the duct wall. It was well isolated from the outside.



(a) Inner duct



(b) Outside duct

(c) Duct with out door unit

Figure (4-2) (a,b&c) Out door unit duct

4-3-2 Electric heaters.

For the purpose of simulating high temperatures during the summer season in Iraq, when temperatures reach more than 45 °C, electric heaters must be used. Electric heaters were placed at the main entrance to the duct, in order to prepare hot air with different temperatures to show the effect of temperatures on the cooling unit. Several finned tube electric heaters were used to facilitate and speed up the heat exchange process through the fins that increase the surface area. The electric heaters, with a total capacity of 15000 watts, were precisely distributed to allow heat exchange as much as possible and reduce the heat factor. The heaters are equipped with alternating current and a constant voltage of 220 volts. The calculation of the electric current required for the heaters to work was neglected because the electric heaters were not used when the cooling unit was working in the summer.

Figure (4-3) Finned tube electric heater

4-3-3 - Variac voltage regulator

The variac is an important device used to control temperature. The Variac works by equipping it with an alternating current and a voltage of 220 volts, so that it in turn produces an alternating DC current as well, but with a variable voltage that is regulated by a manual controller at the top of the device. Electric heaters are supplied with alternating current coming out of the device with variable voltages. In this study, the heaters were equipped with several different voltages ranging from (100-220) volts. To obtain temperatures ranging from (40 - 57.3) °C.

Figure (4-4) Variac voltage regulator

4-3-4 Cellulose pad Layers.

The layers of a zigzag-shaped cellulose pillow were used in this study, the layers were with dimensions (49 * 59) cm, but with different thicknesses (3, 5, 7) cm. These gaskets were placed inside the factory duct for experimental purposes. The location of the filling is between the electric heaters and the condenser coil. These gaskets are equipped with regular quantities of water distributed from the top to the bottom through a duct containing holes of equal distances and size. These gaskets supply the condenser coil with relatively cool and more humidity air when compared to outside air.

Figure (4-5) Cellulose pad layers

4-3-5 Water pump

The water pump prepares the gaskets with the water necessary to moisten them. The water pump was placed in a tank at the bottom of the experiment device, which is equipped with the return water, and it also contains a raft connected to an external source to compensate for the evaporated water from the surface of the filling. The pump operates with an alternating current of (0.1 amp) and a voltage (220 volts), and the current has been neglected in the energy saving calculations for its smallness compared to the current consumed by the air cooling unit.

Figure (4-6) Water pump

4-4 Measurement devices

The refrigeration unit consists of four basic parts and is divided into two parts. The first part (the outer part) consists of three parts together, namely (compressor, condenser, expansion valve). This part was placed inside the duct designed for this experiment. While the second section of the refrigeration unit (the inner piece), which contains the evaporator, was placed outside the duct because it could not be exposed to high temperatures.

While the secondary parts and devices used in the study can be shown as follows:

4-4-1 Thermocouples

Thermocouples are sensors that work in harmony between temperature changes and the voltages supplied by them. A number of thermocouples were distributed inside the test device, starting with measuring the dry and wet temperature of the surrounding air. Sensors were placed after the electric heaters to control and measure the temperature of dry and wet bulbs. After filling, sensors were placed to measure the temperatures of dry bulb and wet bulb. Finally, sensors were placed on the beginning and end of the condenser coil and the beginning and end of the evaporator coil, and the humidification water temperature was measured after controlling its temperature with an electric heater as well. It is worth noting that all thermo-sensors, cables, were manually calibrated using a mercury thermometer and compared with a laser sensor as shown in the pictures below.

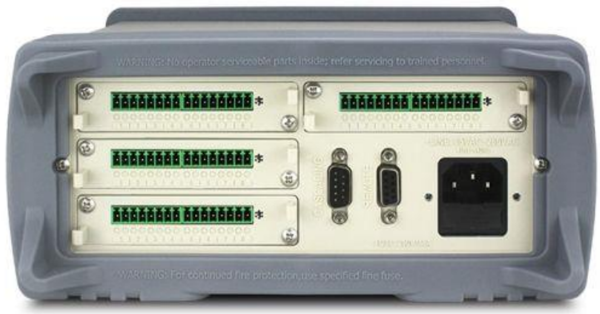
(a) laser temperature sensor (b) Thermocouple

Figure (4-7) Temperature sensor

4-4-2 Detector Data Logger

It is the device used to read the voltages supplied by the thermocouple cables and convert them into digital outputs on the display screen indicating the temperatures at the location of each of the thermocouple sensors. The device works after it is equipped with alternating current and a voltage of 220V, the device works with 0.2%+1c Accuracy according to the manufacturer's data. Thermocouples are all connected together in a regular sequence to be read and recorded correctly without human error when recording.

(A)



(B)

Figure (4-8) (A&B) Detector Data Logger

4-4-3 Water flowmeter

The quantities of water are prepared in variable quantities (100, 125, 150) liters / h to the filling, through a glass water flowmeter. The amount of water is controlled by the club valve, which is located in this study after the glass scale.

Figure (4-9) Water flowmeter

4-4-4 Pressure drop device

The pressure drop measurement device consists of two plastic tubes placed in the upper ceiling of the air duct before and after the filling. The main purpose of measuring the pressure drop is to show the effect of the thickness of the filling on the airflow inside the duct.

Figure (4-10) Pressure drop device

4-4-5 Air flow meter

The air flow meter is one of the important devices in this study because it deals with the quantities of air supplied to the cooling coil and the impact of the pad on the speed and quantity of air. The air speed is read through a small fan at the top of the device that rotates by the air to record the speed on the digital screen of the device in m/s.

Figure (4-11) Air flowmeter

4-4-6 Ammeter

It is a device used to measure the consumption of electric current by any electrical device. The current drained from the air conditioning unit was measured at all recorded temperatures and the effect of temperature change on the drawn current was shown.

Figure (4-12) Ammeter

4-5 Calibration: Calibration is intended to reduce uncertainty and errors in instrumentation due to aging, poor storage, or other causes.

1-Thermocouples and pressure gauges:

have been calibrated by the Standardization and Quality Control Department As in Appendix (A).

2-Flow meter water

The water flow meter was calibrated by means of a graduated vessel and a digital measuring watch, and the flow was recorded for one hour, and the error rate was ±0.23%.

3-Air flow meter

The data of the manufacturer was relied upon, As in Appendix (A).

4-Ammeter:

The ammeter was calibrated by the following equation:(3-1) by assuming that the current is of unknown value and the error rate is ± 0.7%

4-6 Experimental procedure:

The work was to run the test device after completing the installation of the split-type air conditioner, the outdoor unit was installed in the outer space, but the condenser was surrounded inside the duct to control the temperature and humidity control entering it.

1- The duct, starting from the point of entry of the air current, includes electric heaters with a total capacity of 15000 watts. These heaters work on heating the outside air to work similar to the outside conditions in the summer. Sensors for dry and wet temperatures for the outside air and for the air after the electric heaters were installed to know the temperatures and water vapor was added to simulate a closer simulation of the external weather conditions in the summer season.
2- After 30 minutes from start the hot air was passed directly to the condenser and the high pressures in the condenser and low pressures in the evaporator were recorded, as well as the roasting temperature

after the compressor and the temperature after the condenser. The temperature entering and leaving the evaporator was also recorded before using the evaporator condenser.

3- When using the evaporator condenser with pad thickness (3,5,7)cm ,the hot air was passed over a pad of 3 cm thickness and with different amounts of water (100, 125, 150) liter/h. At this stage, the difference between the temperatures of the dry and wet bulbs of the air before and after the pad is measured, as well as the pressure difference when using the filling. The electrical current was measured by the air conditioner, in addition to the current of the water pump used to spread water through the nozzles, which distributed water in equal quantities to all parts of the filling.
4- The previous method was prepared as in (3) above, but by using a filling of 5 cm thickness, and the same previous decisions were taken.
5- The hot air was passed over a 7 cm thick pad before entering the condenser. The calculated variables were also recorded in the blister (3) above.

It should be noted that a electric heater (1kW) was used to heat the feedback water used in the wetting process of the pad, so that the simulation process was carried out very accurately, as the water temperature was fixed to be 35°C, but this temperature varies at each operating mode according to the volumetric flow amount and the thickness of the pad.

Chapter Five

Results and Discussion

Chapter Five

Results and Discussion

5.1 Introduction

The measuring are taken when the system under test reached its steady state, which was after approximately 30 minutes. The readings include parameters (dry bulb temperature, wet bulb temperature, air velocity, water quantity and, pad thickness) which are included in the tables described in appendix B. The measurements and results were classified according to three categories:

1- In terms of the effect of temperature.

2- In terms of the effect of the thickness of the filling.

3- In terms of the effect of volumetric flow of water.

5-2 Experimental results

When comparing the results obtained in Tables (B-1, B-2, B-3, B-4) between the system before and after improvement and for different thicknesses of the used bandage. It turns out that:

1- The coefficient of performance (COP) of the basic system between temperatures ranging from (38.8 - 50) °C was (3.5 - 2.8), respectively. It stopped working when the temperature rose to more than 54°C. While the COP ranged between (3.73 - 3.68) for temperatures ranging from (44.1 - 50.5) °C when using the evaporative condenser with a thickness of 3 cm and a volumetric water flow of 100 liters / h, and the amount of any increase in the COP was estimated (20%). The average energy consumption per unit has been reduced after optimization, bringing the energy savings up to 0.7%.

2- With increasing the thickness of the pad to 7 cm with the same other parameters of temperature and volumetric flow of water, the amount of improvement of the COP was up to 20.3%, while the energy saving, in this case, was up to 0.66%.

3- While the COP was better than all previous cases when the thickness of the filling was 5 cm and with the same other parameters of temperatures and volumetric flow of water. The increase in the COP increased to 25.2% and the energy savings increased to 13.2%.

Considering data shown in Tables (B-5, B-6, B-7), the results can be clarified as follows:

1- The COP increases with greater energy savings when comparing the pre-improvement unit with the same unit after using the evaporative flow condenser The volume of water is 125 liters / h . Where the COP increased at a temperature of (49) °C from (3) to (3.68), where the rate of increase is 20.3%. While there was an energy saving of 4.5%.

2- The COP increases with the increase in the thickness of the pad when using the 7 cm thickness pad, and the volumetric flow of water is 125 liter /h. Where the increase in the COP in this case compared to the base system at a temperature of (48) °C from (3.12) to (3.6), and the rate of increase is 21%. While the energy savings amounted to 6.7%.

3- When comparing the COP and energy savings when using the 5 cm thick pad and the volume flow rate of water is 125 liter / h with the basic unit. Where the increase in the COP in this case from the basic system at the temperature (48) °C from (3.12) to (3.74), and the rate of increase is up to 21.2%. While energy savings amounted to 13%.

Considering data shown in Tables (5-8, 5-9, 5-10), the following is evident:

1- The COP increases with the increase in energy savings when using a volumetric flow of water up to 150 liter/h when using the evaporative condenser with a pad thickness of 3 cm. (50) °C, from (2.8) to (3.69), where the rate of increase in the COP was 22%, while saving energy by 14%.

2- The COP increases with the thickness of the pad 7 cm and the amount of water 150 liter / h, where the COP increases from the COP of the basic system at the temperature (49 °C). The COP increases from (2.9) to (3.64), where the percentage increase is 17.3%. While energy savings amounted to 15%.

3- While when using a pad with a thickness of 5 cm, the results were unexpected, as the device continued to work at a temperature of 57 °C, which was not achieved with all previous experiments with the rest of the pad and the rest of the volumetric flows of water. Where the COP at a temperature of 48 °C in the basic system (2.95), while it increased when using the evaporative condenser with a thickness of 5 cm to reach (3.64). The rate of increase in the COP is estimated (18%), while the energy savings increased by 22.4%.

5-2-1 The effect of air temperature

Figure (5-1) below shows the effect of air temperature on the COP with the use of an evaporative condenser at a water volume flow rate of 100 liters / h and a constant air speed of 4.5 m / s. The graph shows the difference in the COP increased significantly when using different thicknesses of pad. The results showed that the best pad used was 5 cm thick.

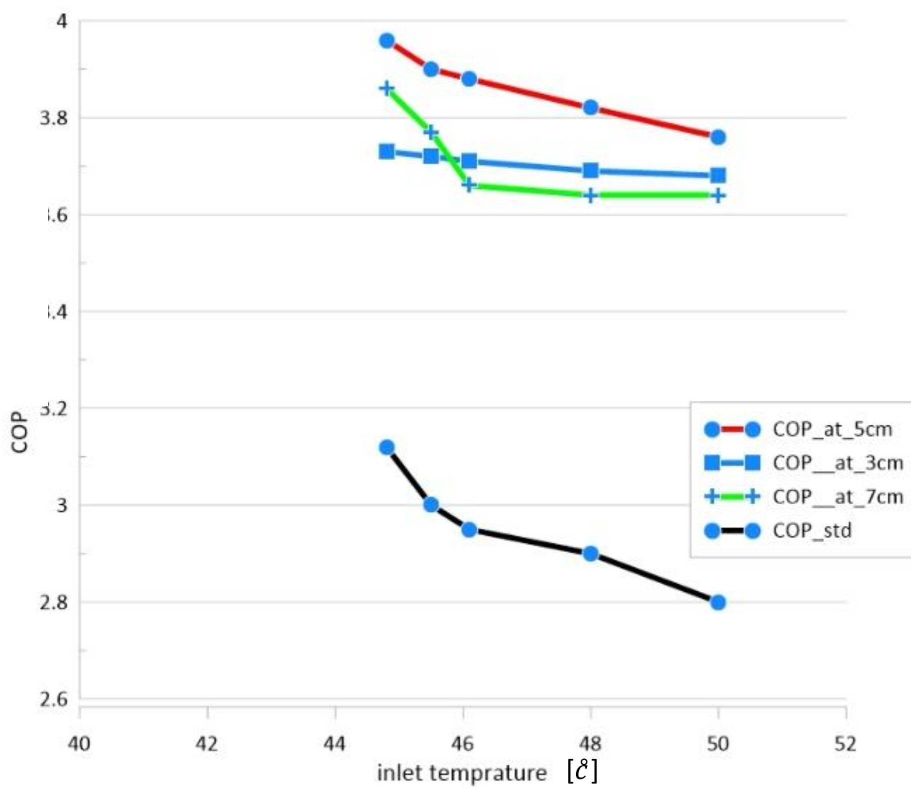


Figure (5-1) Effect of the air inlet temperature with water 100 liters / h on the coefficient of performance of cycle.

Figure (5-2) represented the relationship of occupancy with temperature when using the system without adding the evaporative condenser and comparing it with the use of the evaporative condenser and for the different thickness of the fillings. Where it shows that the least energy depletion and less work when using the indirect evaporative condenser with a thickness of 5 cm.

In addition, the energy of the condenser and the evaporator can be represented with the change of temperatures in the diagrams (5-3, 5-4), where it shows that the best evaporative condenser is when using the 5 cm filling.

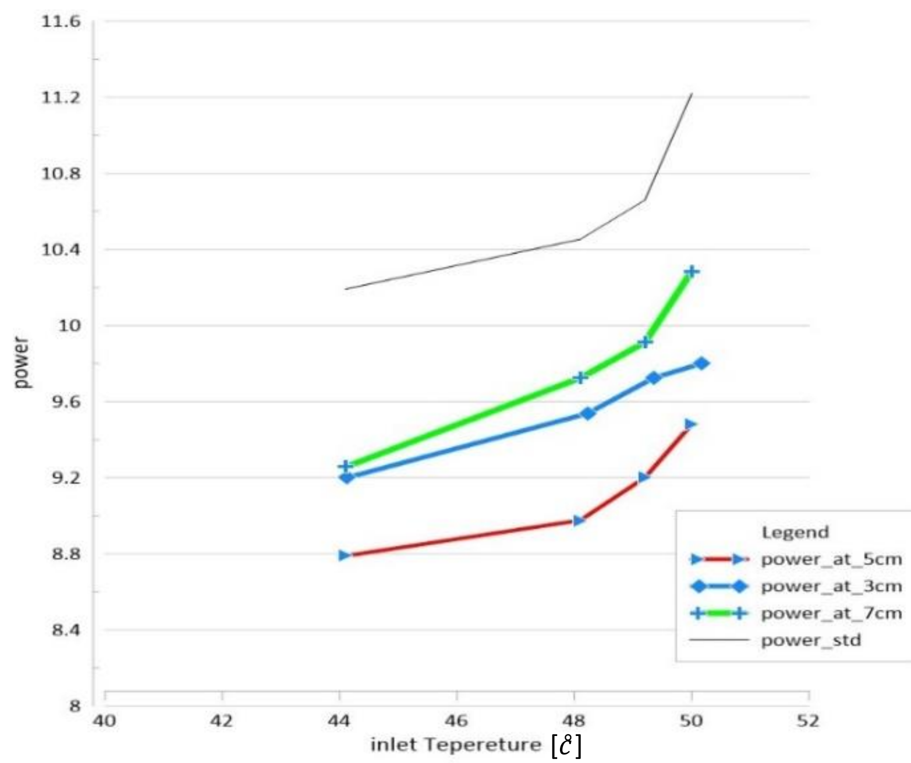


Figure (5-2) Effect of the air inlet temperature with 100 liter / h water on the power of air condition unit.

Figure (5-3,5-4,5-5) shows that the coefficient of performance has remained stable when using a 5cm pad even at high temperatures. While it decreases significantly at higher temperatures using other pad.

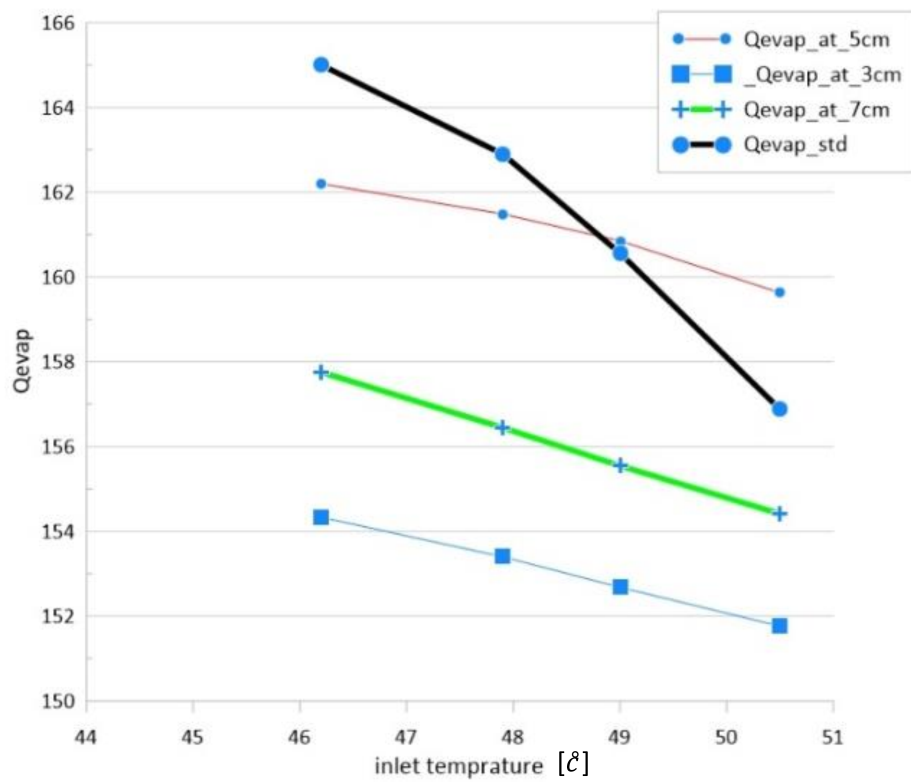


Figure (5-3) Effect of the air inlet temperature cycle with 100 liter / h water on the Q evaporator for 3cm, 5cm and 7 cm pad thickness with standard cycle.

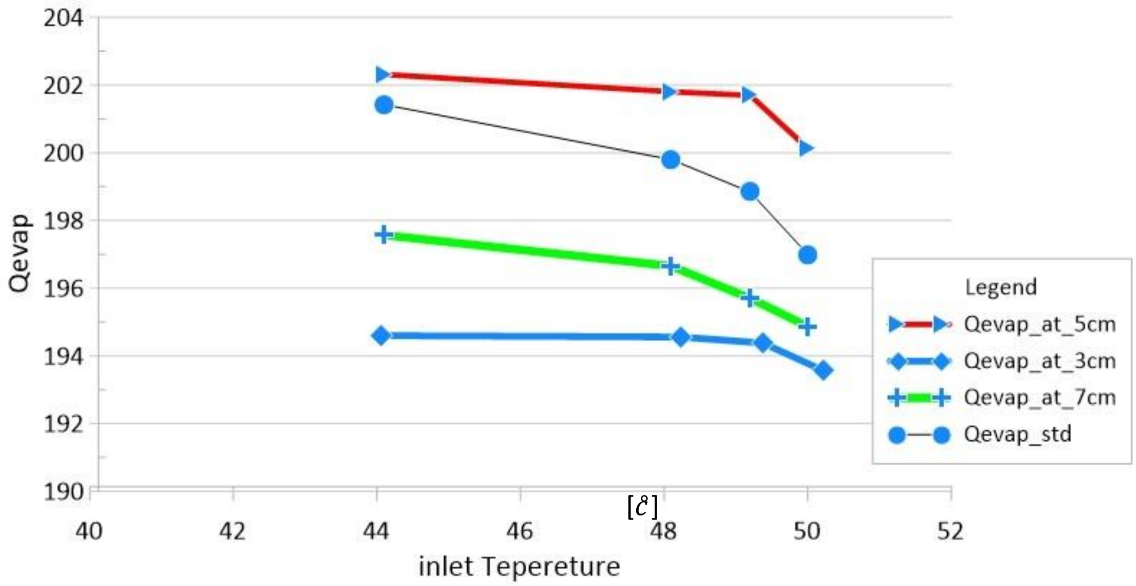


Figure (5-4) Effect of the air inlet temperature with 100 liters / h water on the Q condenser for 3cm, 5cm and 7 cm pad thickness with standard cycle.

Figure (5-5) show the relationship of the performance coefficient with temperatures when using the three fillings with a water volume of 125 liters / h

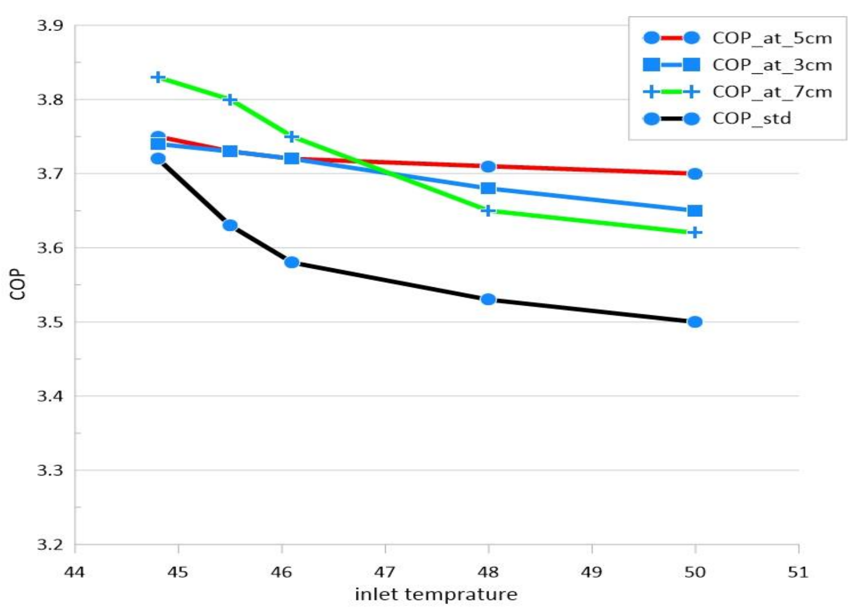


Figure (5-5) Effect of the air inlet temperature with 125 liter / h water on the coefficient of performance for 3cm, 5cm and 7 cm pad thickness with standard cycle.

Figure (5-6) shows the decrease in occupancy when using an evaporative condenser. It also shows that the pad with a thickness of (5) cm is the most efficient in terms of reducing the required work even with temperatures rising to more than (50) °C.

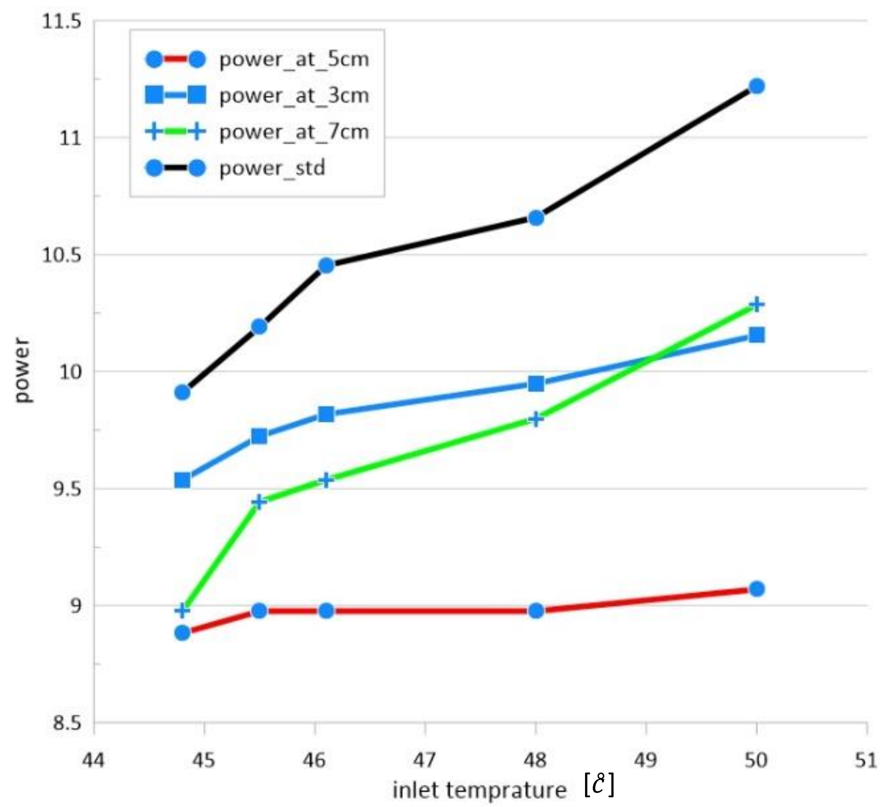


Figure (5-6) Effect of the air inlet temperature with 125 liter / h water on the power of air condition unit

Figures (5-8) and (5-9) show that the largest energy of the condenser and evaporator at a volumetric water flow of 125 liters / h was when using the evaporative condenser with a thickness of 5 cm, while the lowest energy when using the evaporative condenser was 7 cm.

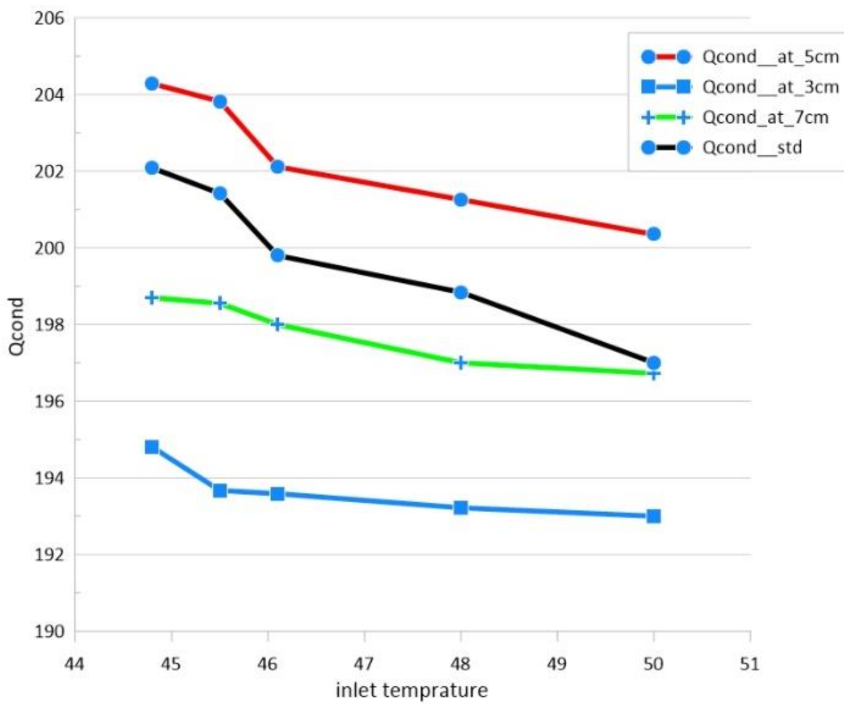


Figure (5-8) Effect of the air inlet temperature on Q condenser at 125 liters / h water

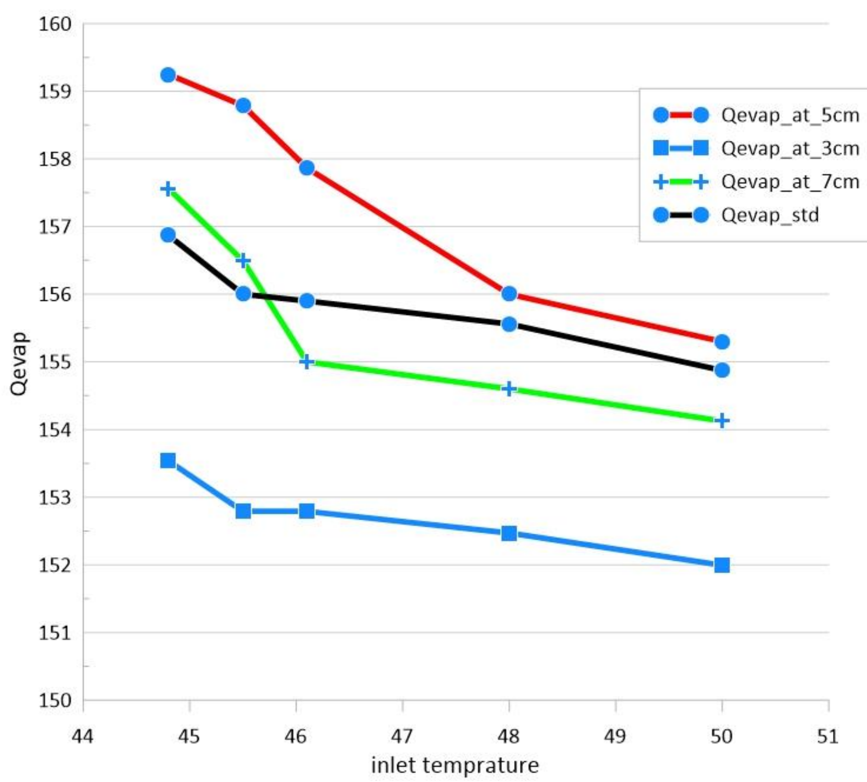


Figure (5-9) Effect of the air inlet temperature on Q evaporator at 125 liters / h water

Figure (5 -10) shows that the COP reached the highest value when using the 3 cm padding, but the system quickly stopped working when the temperature reached above 50 °C. While the work continued with a high performance coefficient when using the 5 cm pad, even with the temperature rising to approximately 57.3 °C. While the main system stopped working before using the evaporative condenser when the temperature rose to above 50 °C.

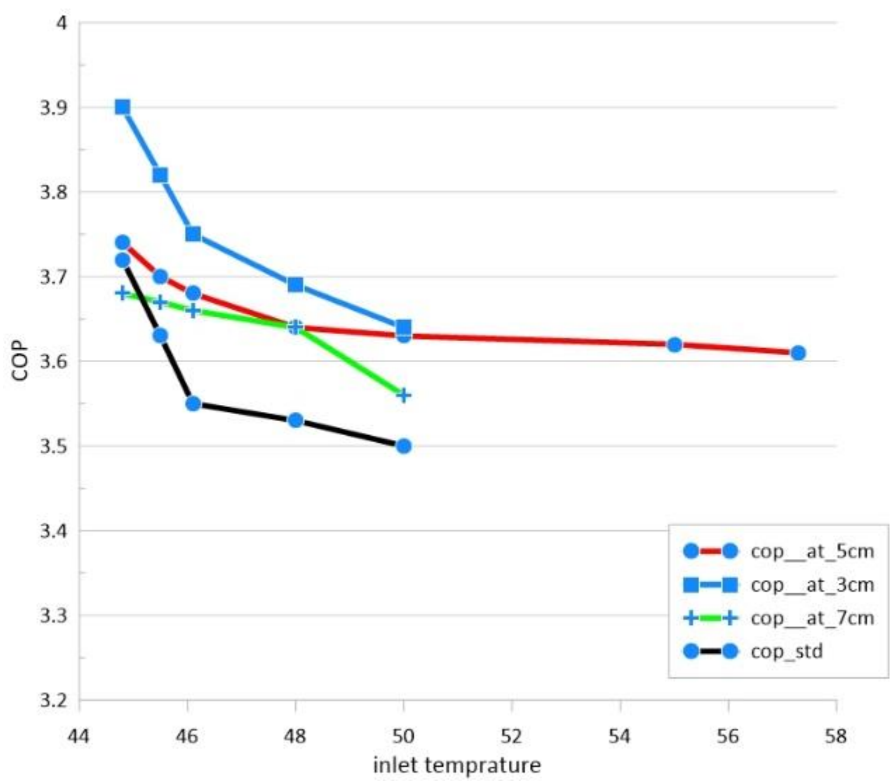


Figure (5-10) Effect of the air inlet temperature on performance factor at 150 Liters /h water

The Figure (5 -11) represents the graph between the consumed work with the change in temperature, where it shows that the basic cycle is the most draining of the work while decreasing gradually with the use of the evaporative condenser. The minimum depletion of the work piece when using a pad was 5 cm, even with a temperature increase of about 57.3 ° C. While the main system stopped working before the evaporative condenser was used when the temperature rose above 50°C.

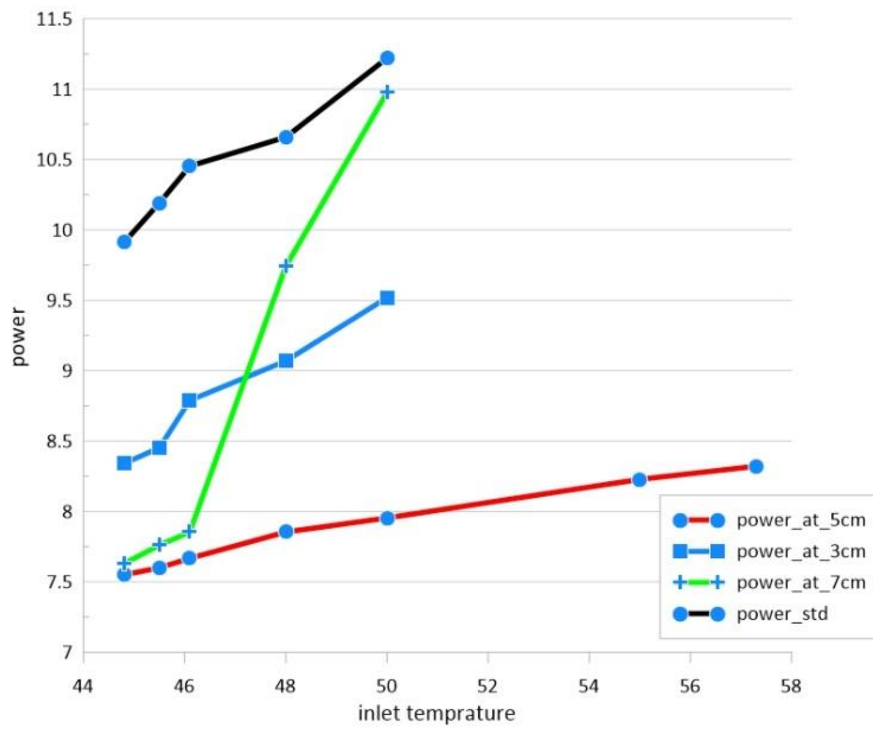


Figure (5 -11) Effect of the air inlet temperature on the power of air condition unit with 150 Liters /h water

Figure (5-12, 5-13) represents the graph between the energy of the evaporator and energy of the condenser with the change in temperature. Where it was found that the cycle with the thickness of the pad 7 cm is the most energy at temperatures that do not exceed 47 °C. While the cycle with the thickness of the pad 5 cm is the most stable even with high temperatures, which reach 57 °C. And, then, followed by the cycle with the thickness of the pad 3 cm in terms of stability in the energy of the evaporator.

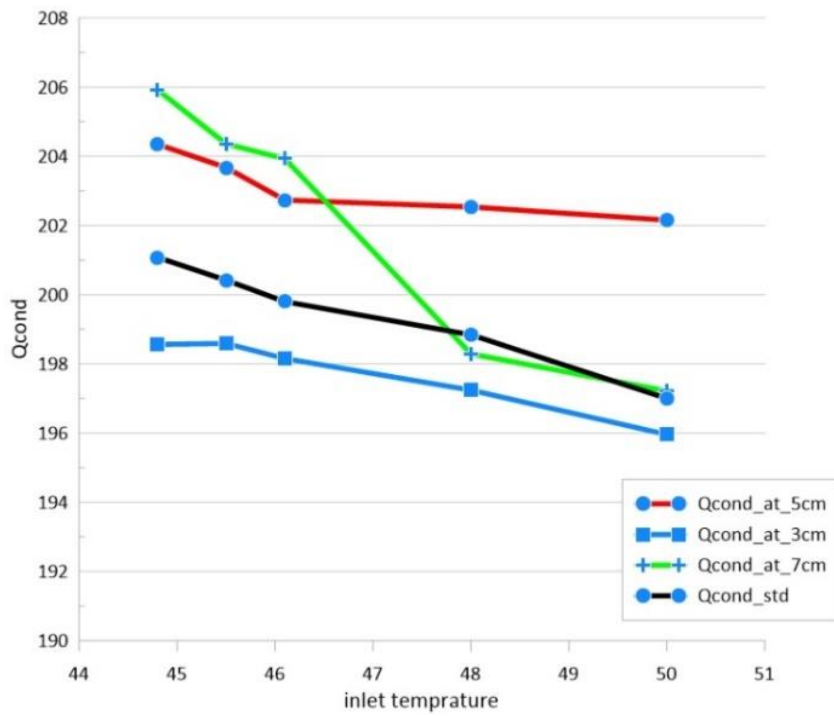


Figure (5-12) Effect of the air inlet temperature on Q condenser at 150 Liters/h water

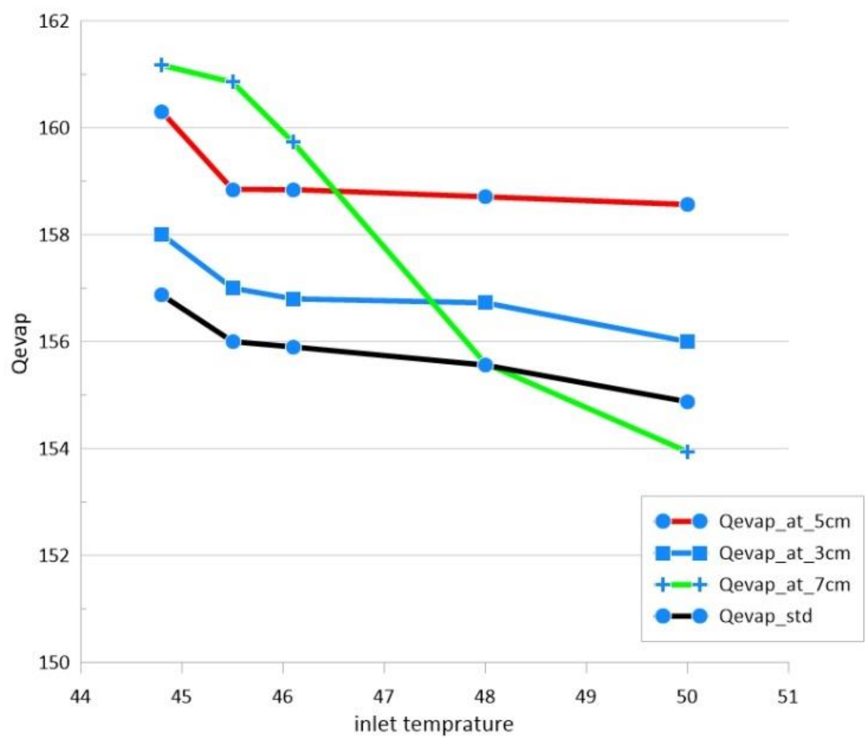


Figure (5-13) Effect of the air inlet temperature on Q evaporator at 150 Liters /h water

The pressure drop was also compared when using different pads, which are shown in Figure (5-15) .

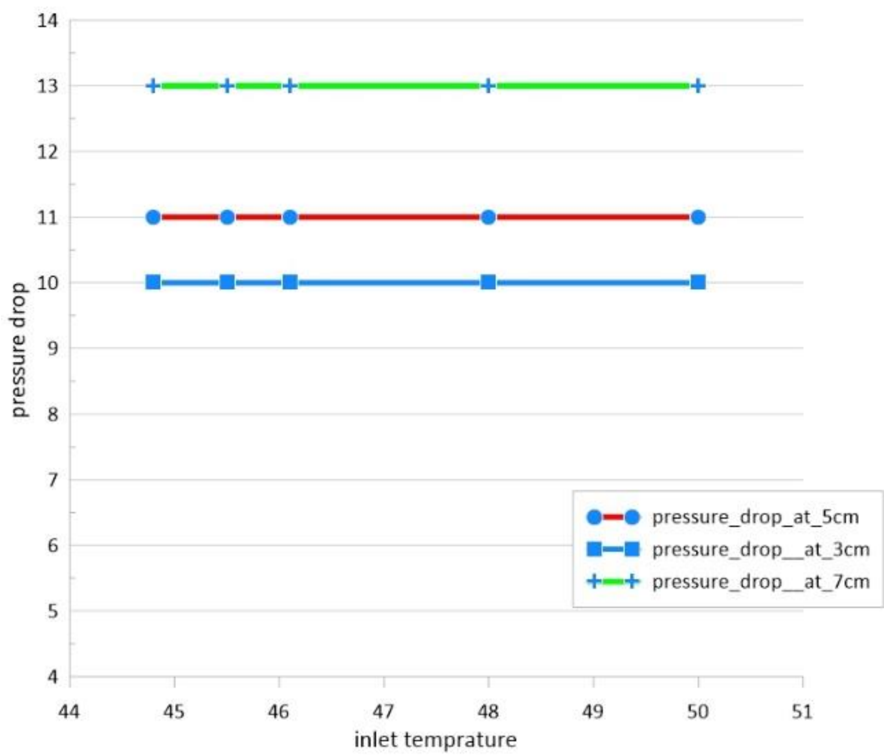


Figure (5 -15) Effect of the air inlet temperature pressure drop

Also, figures (5-16, 5-17, 5-18) of the change of current with the change in temperatures between the main system and the system was drawn with the use of a pad and water quantities (100, 125, 150) liters / h, when using different pads with a thickness of (3, 5, 7) cm, where it appears from the figures that the unit with evaporative cooling consumes less current than the original unit at all outside temperatures.

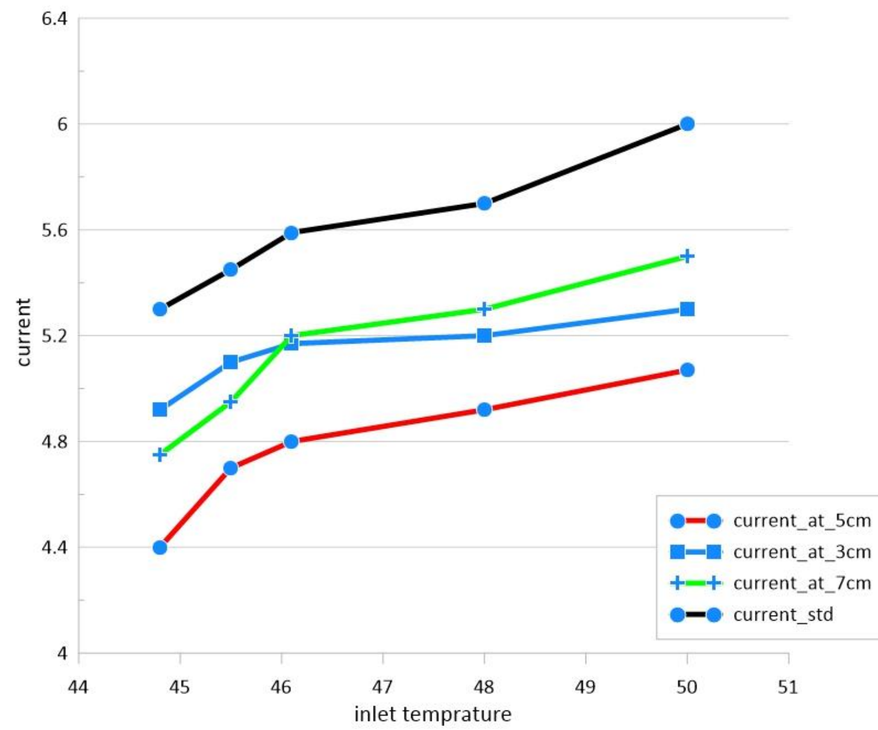
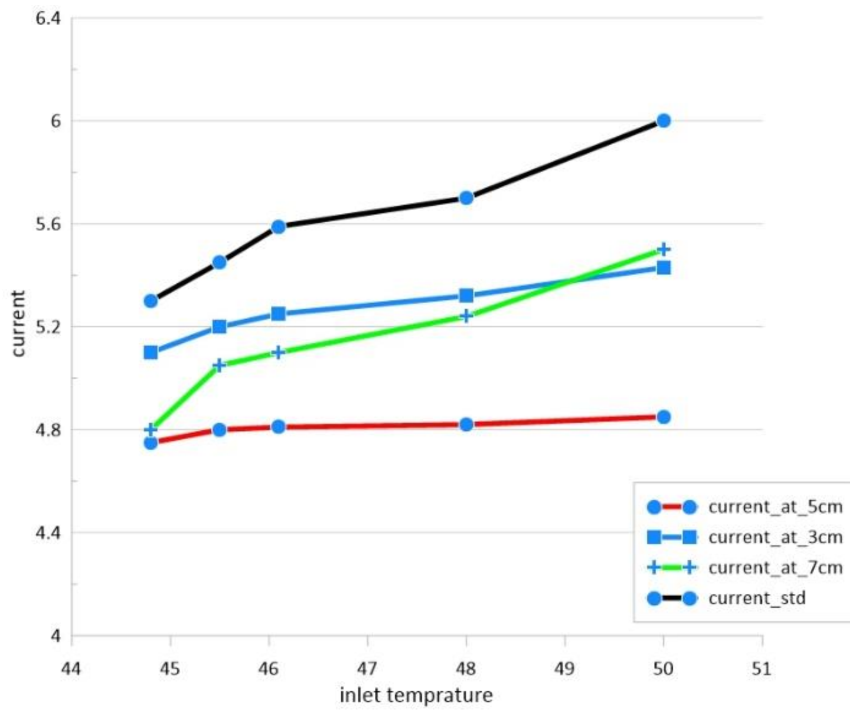


Figure (5 -16) Effect of the air inlet temperature on current at volume flow rate 100 liter/h



(5 -17) Effect of the air inlet temperature on current at volume flow rate 125 liter/h

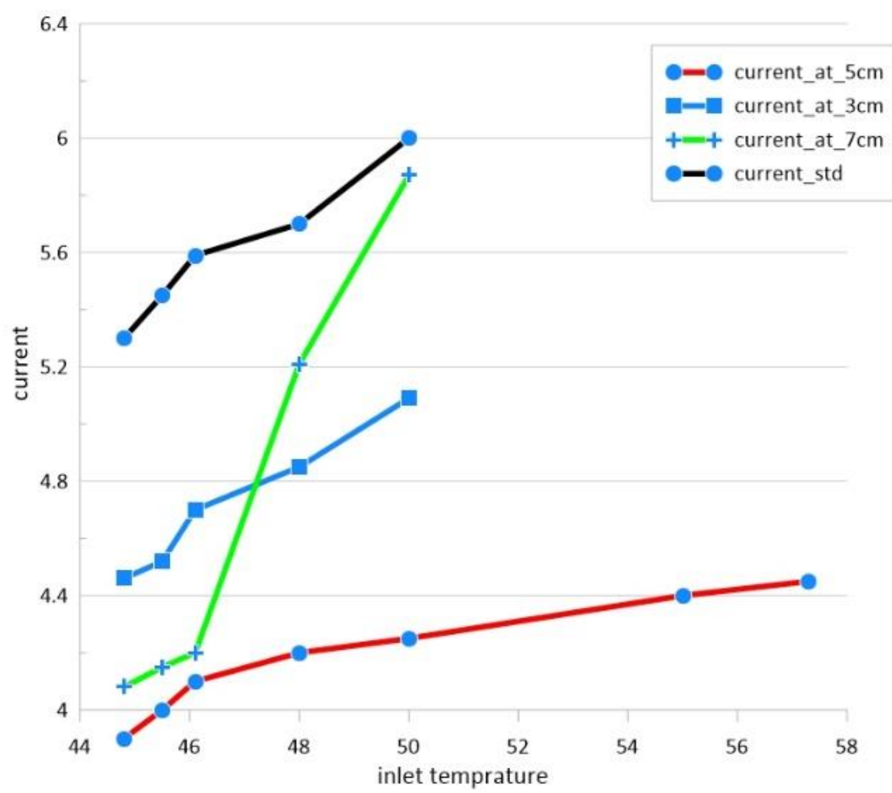


Figure (5 -18) Effect of the air inlet temperature on current at volume flow rate 150 liter/h

5-2-2 The effect of water flow rate.

Figure (5-19, 5-20, 5-21) shows the effect of the volumetric flow of water on the COP of the unit using an evaporative condenser with a thickness of (3 cm). It shows that the flow of water has a significant impact on the performance of the pillow itself, and thus its effect on the air conditioning unit. The results indicate that the best flow rate for this pillow is 150 L/h, and a constant air velocity of 4.5 m/s.

In figure (5-20) shows that the volumetric flow of 100 liter/h accompanies the highest performance of the unit and decreases by increasing the volumetric flow to (125, 150) liters / h when using the pad (5 cm).

While we find that the volumetric flow of 100 liters / hour accompanies the highest performance of the unit when using the pad (7 cm) as well, but at the temperature exceeding 50 °C and less than 45 °C.

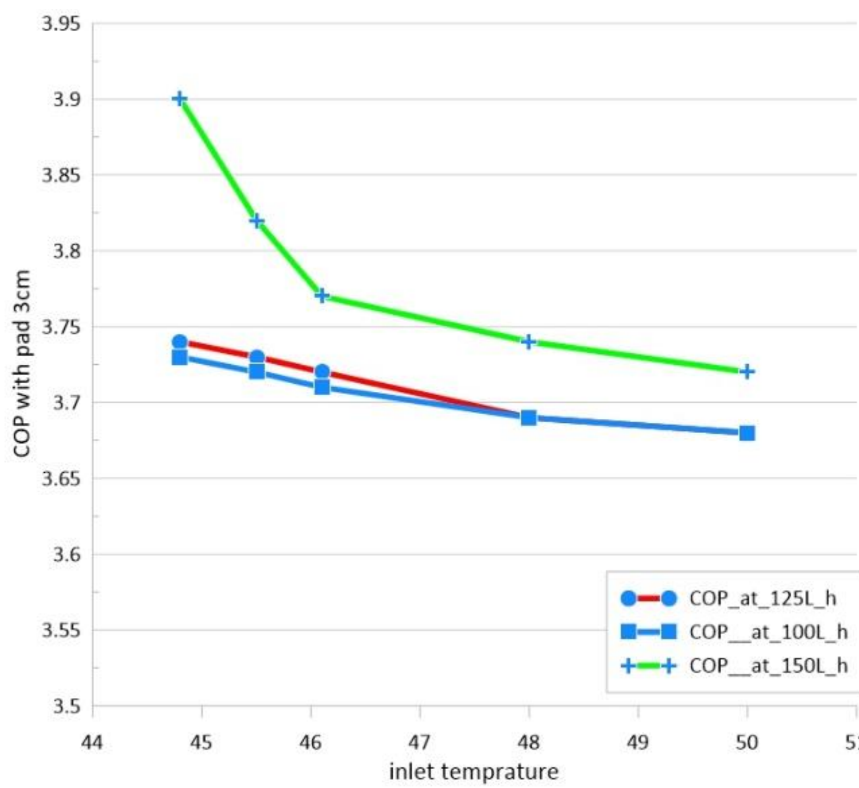


Figure (5 -19) Effect of the air inlet temperature on performance coefficient for unit with 3cm pad at different volume of water (100,125,150) liters /h

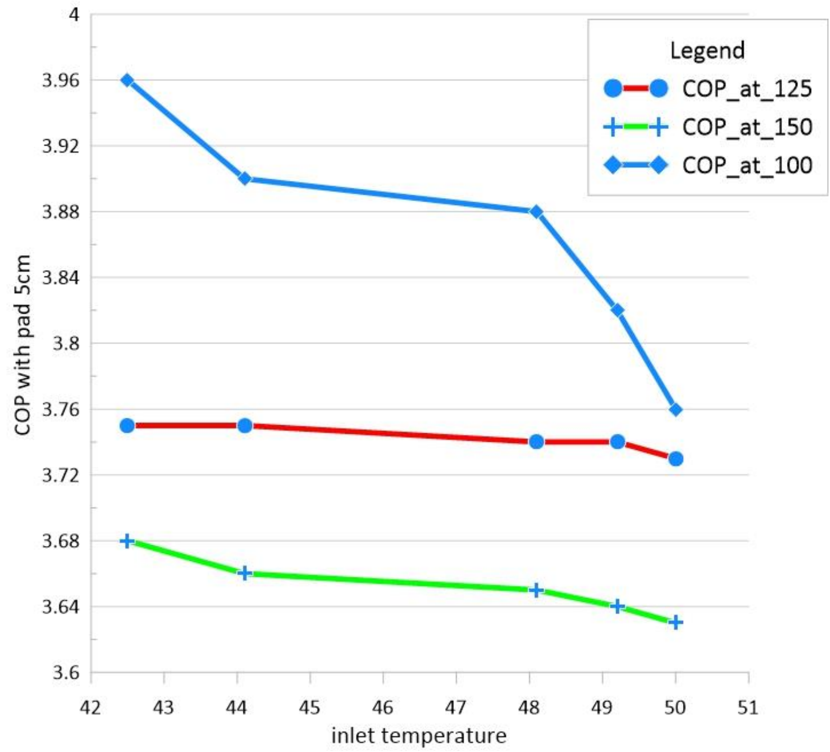


Figure (5 -20) Effect of the air inlet temperature on performance coefficient for unit with 5cm pad at different volume of water (100,125,150) liters /h

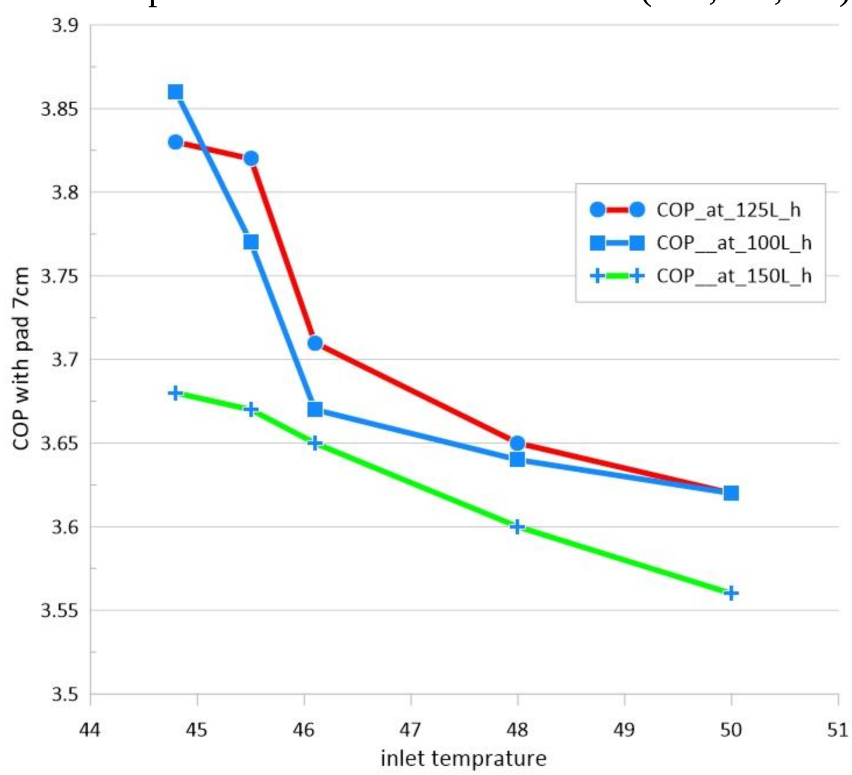


Figure (5 -21) Effect of the air inlet temperature on performance coefficient for unit with 7cm pad at different volume of water (100,125,150) liters /h .

Figure 5-22 shows the effect of the volumetric flow of water on the current using an evaporative condenser with a thickness of 3 cm. It shows that the flow of water has a significant effect on the current consumption using the same pad, . The results indicate that the best flow rate for this pillow is 150 liters /h, and a constant air velocity of 4.5 m/s. Also, the volumetric flow of 150 liters / h is accompanied by a decrease in the current consumption of the rest of the pads (5, 7) liters / h. as shown in Figure (5-23,5-24) .

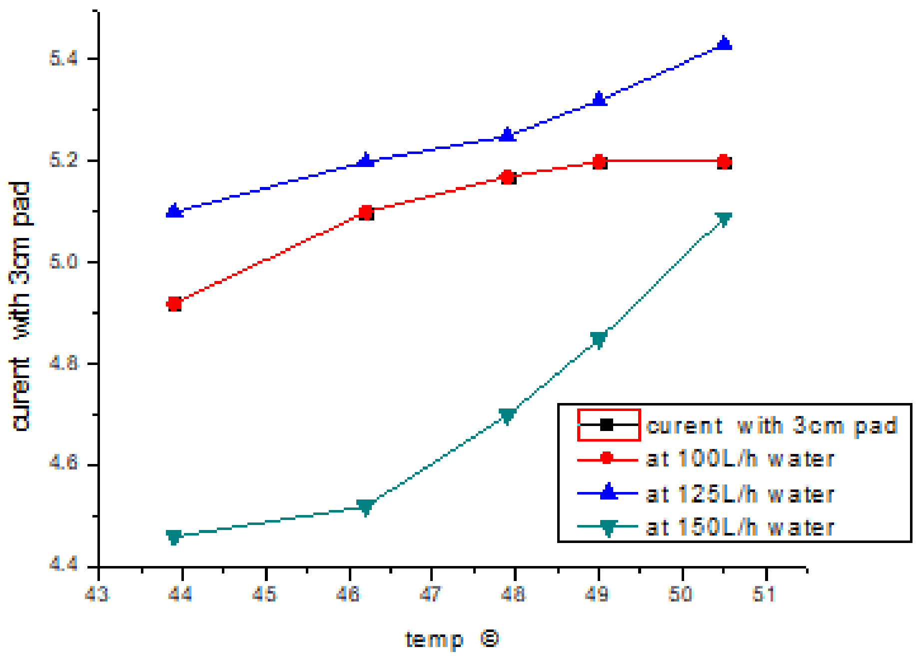


Figure (5 -22) Effect of the air inlet temperature on current for unit with 3cm pad at different volume of water (100,125,150) liters /h

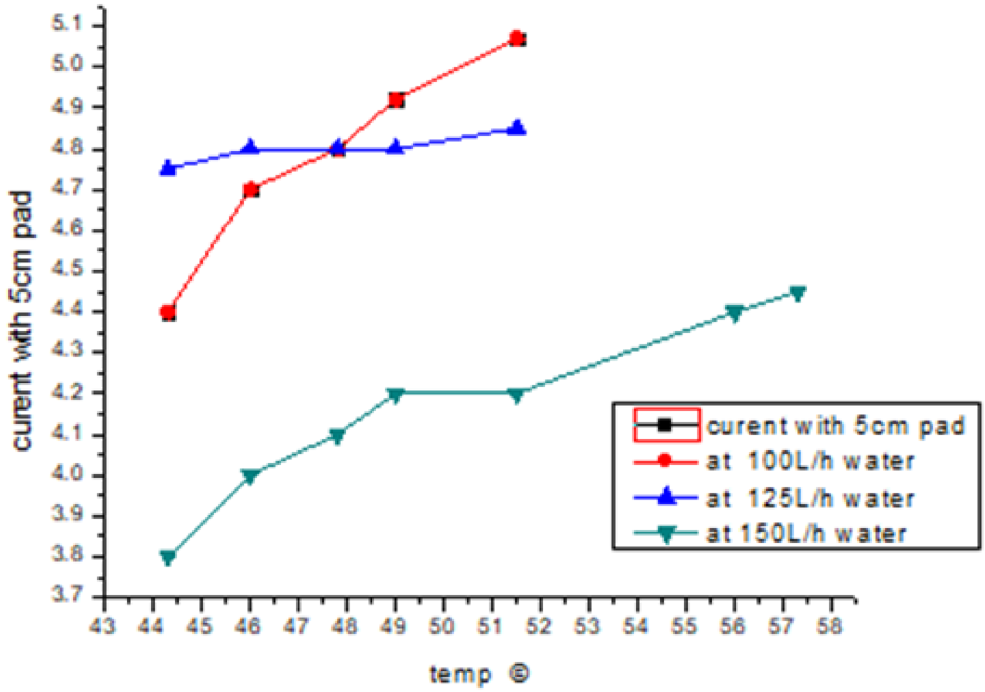


Figure (5 -23) Effect of the air inlet temperature on current for unit with 5cm pad at different volume of water (100,125,150) liters /h

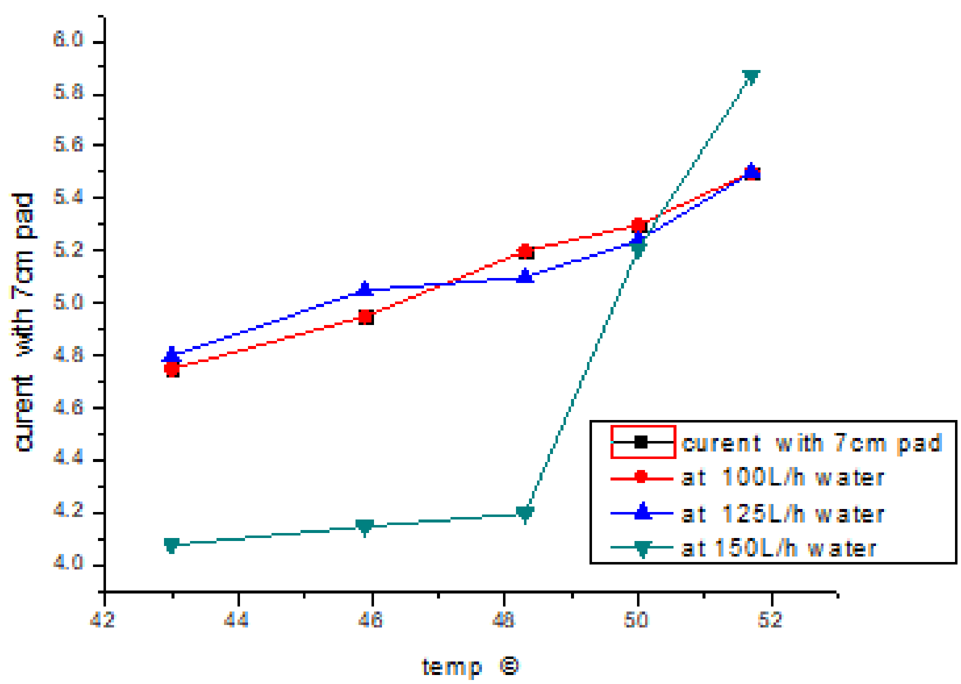


Figure (5 -24) Effect of the air inlet temperature on current for unit with 7cm pad at different volume of water (100,125,150) liters /h

Figure (5-25) shows the effect of the temperature at the air inlet on the condenser temperature of the 3-cm pad unit at a volumetric flow of water (100,125,150) liters/h. The results show that the temperatures are almost equal at lower temperatures From (44 °C) and more than (50 °C), while Figure (5-26, 5-27) shows that there is a large difference between the temperatures when using variable volumetric flows of water with the thickness of (5,7) cm evaporative condenser .

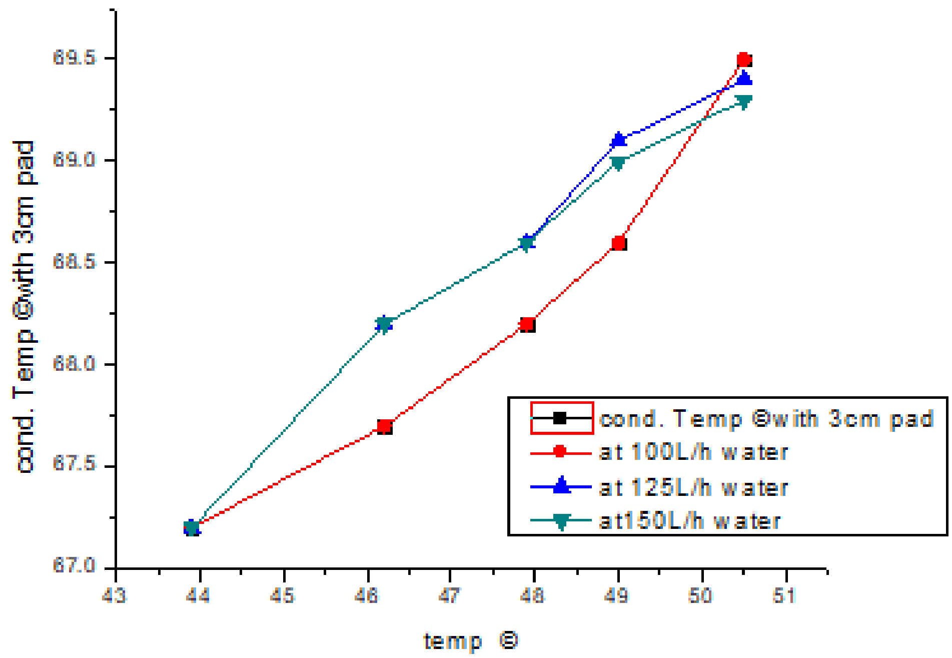


Figure (5 -25) Effect of the air inlet temperature on condenser temperature for unit with 3cm pad at different volume of water (100,125,150) L/h

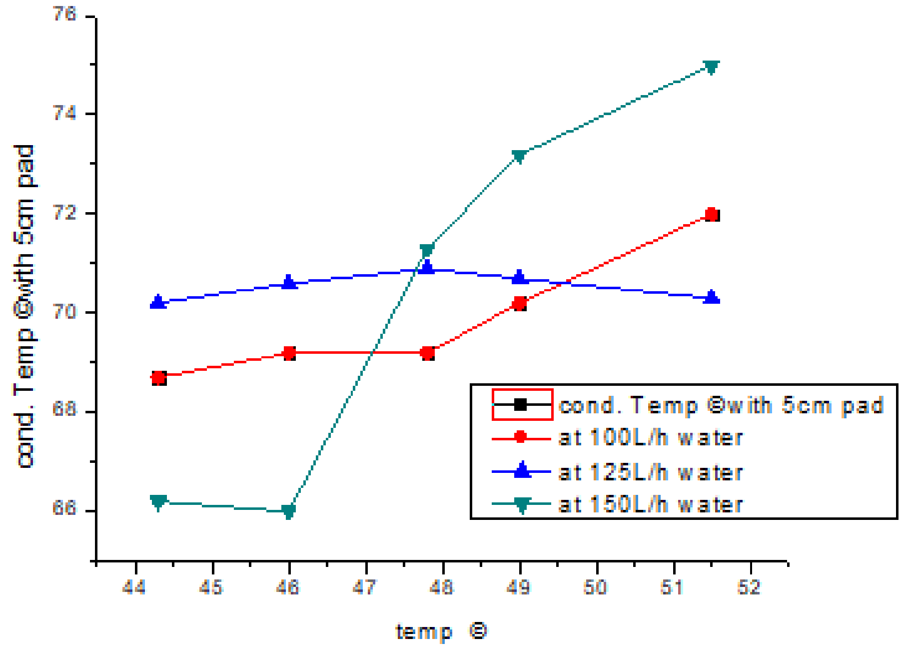


Figure (5 -26) Effect of the air inlet temperature on condenser temperature for unit with 5cm pad at different volume of water (100,125,150) Liters/h

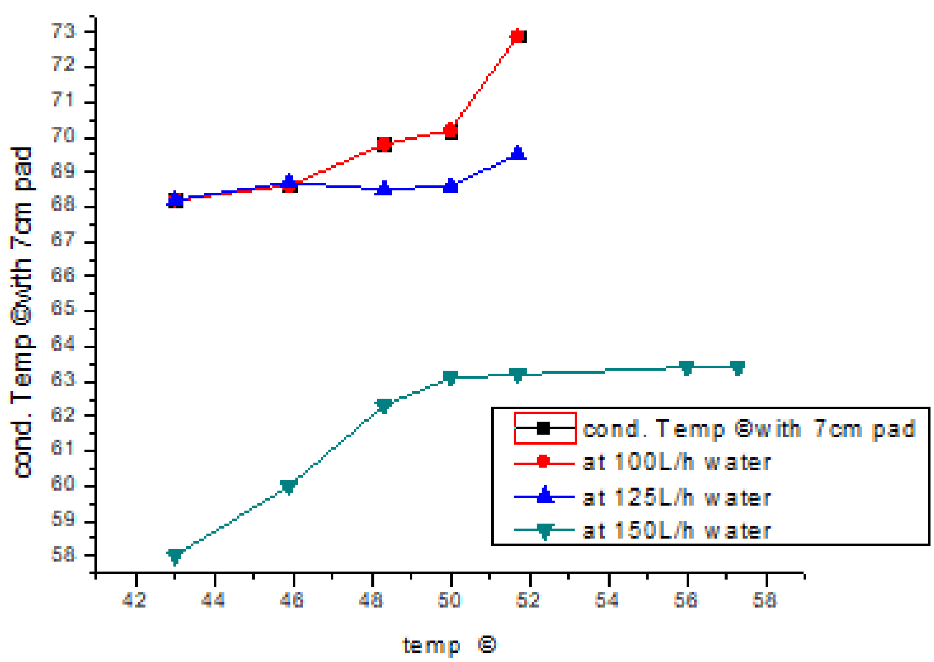


Figure (5 -27) Effect of the air inlet temperature on condenser temperature for unit with 7cm pad at different volume of water (100,125,150) Liters/h

5-2-3 The effect of cellulose pad thickness

Figure (5-29) shows the effect of temperatures on the pressure inside the condenser using an evaporative condenser with a thickness of (3, 5, 7) cm. It shows that the pad with a thickness of (5) cm has the lowest pressure inside the condenser at a volumetric flow of 100 liters / h. While Figure (5-30) is the effect of temperatures on the pressure inside the condenser using an evaporative condenser with a thickness of (3, 5, 7) cm. It shows that a pad with a thickness of (5.7) cm has less pressure inside the condenser than a pillow (3 cm) at a volumetric flow of 125 liters /h.
While Figure (5-31) shows the effect of temperatures on the pressure inside the condenser using an evaporative condenser with a thickness of (3, 5, 7) cm. It shows that a pad with a thickness of (7) cm has less pressure inside the condenser than a pad (3.5) cm at a volumetric flow of 150 liters/h.

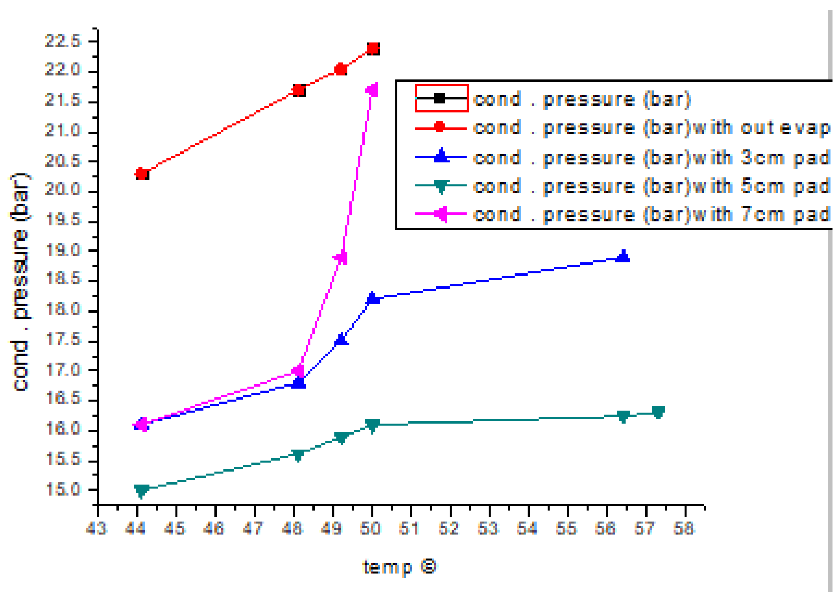


Figure (5 -29) Effect of the air inlet temperature on condenser pressure for stander unit at 100 Liters/h

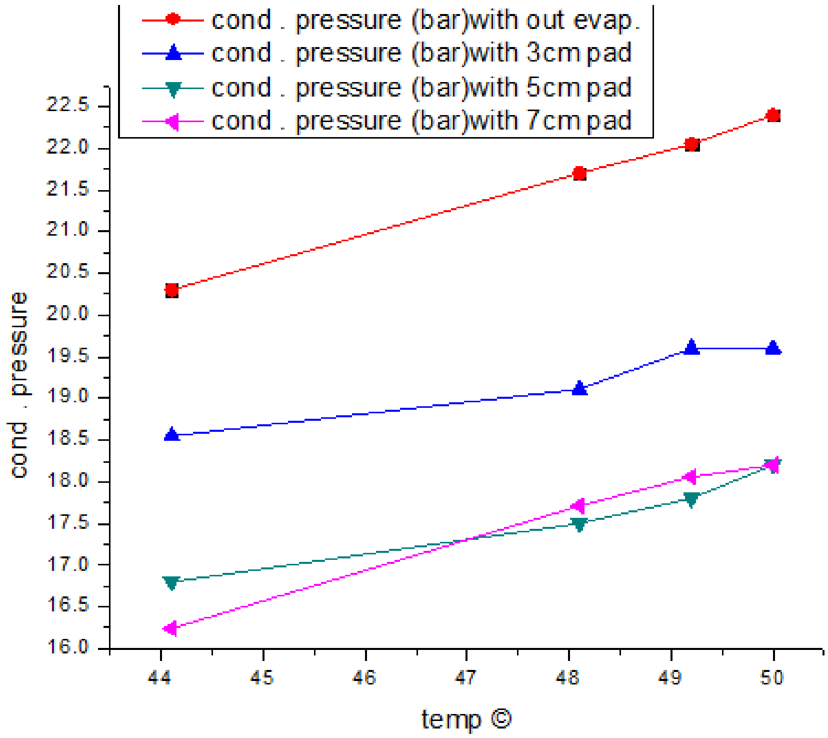


Figure (5 -30) Effect of the air inlet temperature on condenser pressure for unit with evaporator condenser at 125 Liters/h

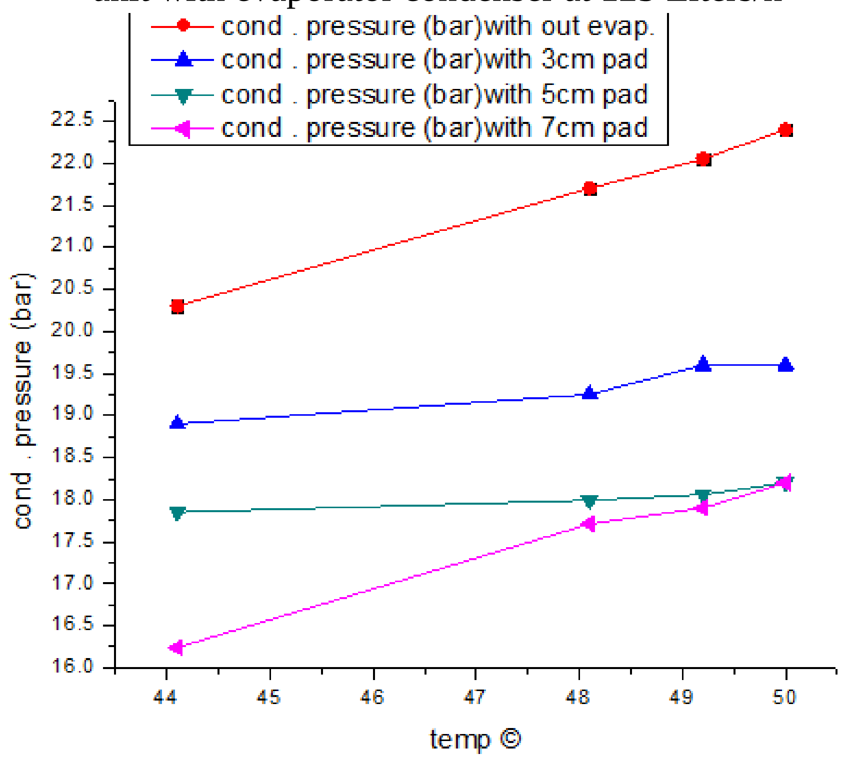


Figure (5 -31) Effect of the air inlet temperature on condenser pressure for unit with evaporator condenser at 150 Liters/h

Figure (5-32), (5-33) indicate the effect of temperatures on the evaporator pressure, as it turns out that the evaporative condenser is (3, 5, 7) cm thick. It shows a significant drop in evaporator pressure and that the (5.7) cm thick pad has the lowest pressure inside the evaporator less than a (3) cm pad at a volumetric flow of 100 liters/h. While Figure (5-34) shows that a pad with a thickness of (5) cm has a pressure inside the condenser less than a pad (3.7) cm with a volumetric flow of 150 liters/h.

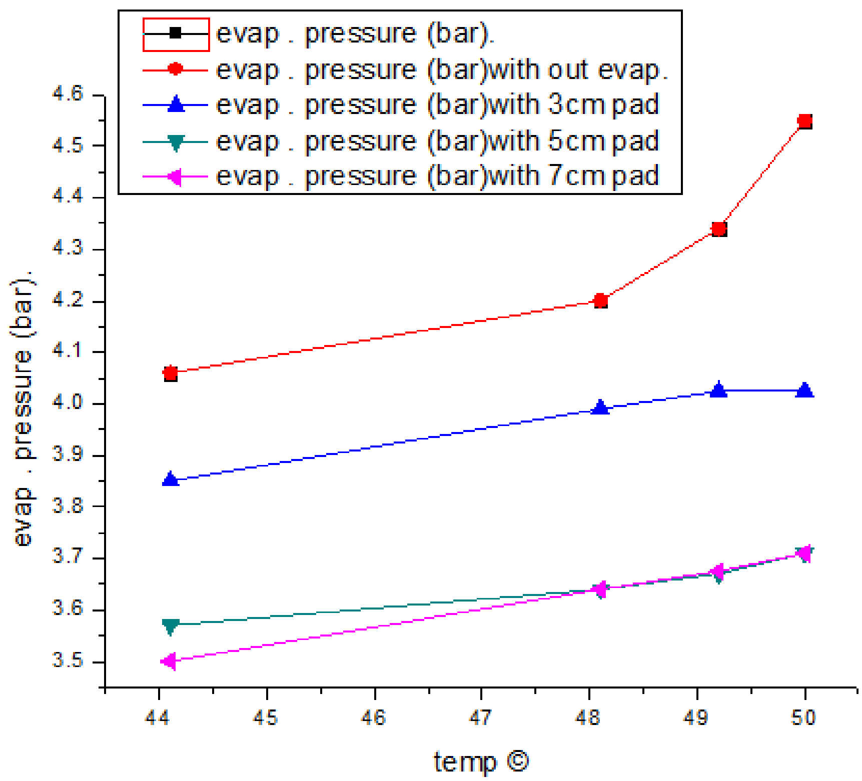


Figure (5 -32) Effect of the air inlet temperature on evaporator pressure for unit with evaporator condenser at 100 liters/h.

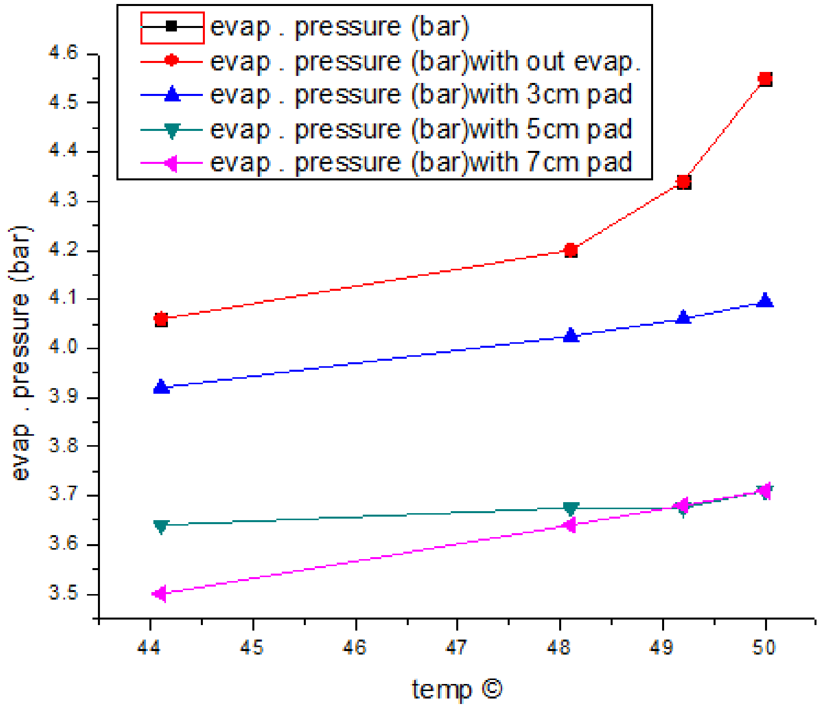


Figure (5 -33) Effect of the air inlet temperature on evaporator pressure for unit with evaporator condenser at 125 liters/h.

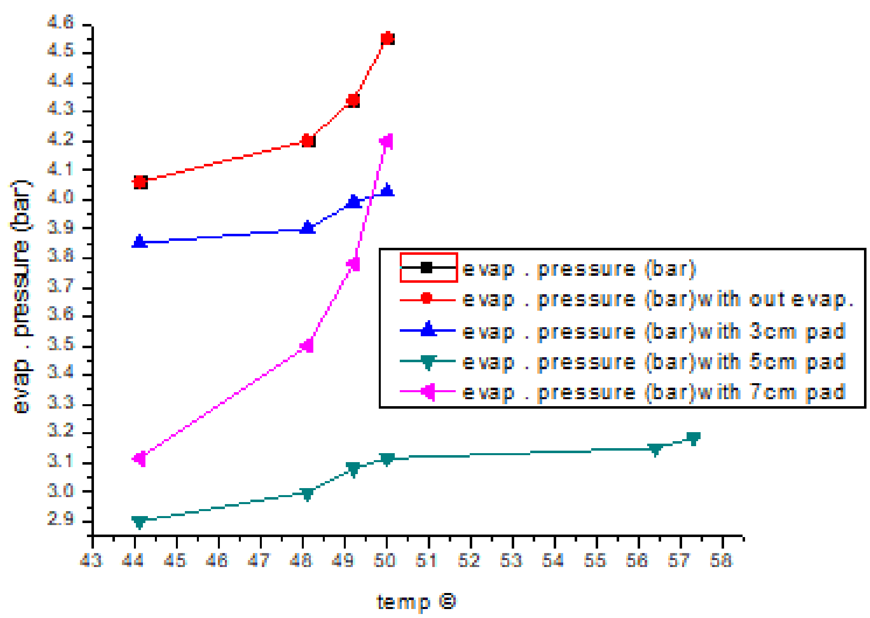


Figure (5 -34) Effect of the air inlet temperature on evaporator pressure for unit with evaporator condenser at 150 liters/h.

Figure (5-35), (5-36), (5-37) indicates the effect of the pad on the outside air with changing different amounts of water volume flow (100, 125, 150) liter/h. The diagrams show that when the volumetric flow of water increases, the temperature decreases by a larger amount. Also, the pad with a thickness of (5) cm gives the best results in all volumes of water flow.

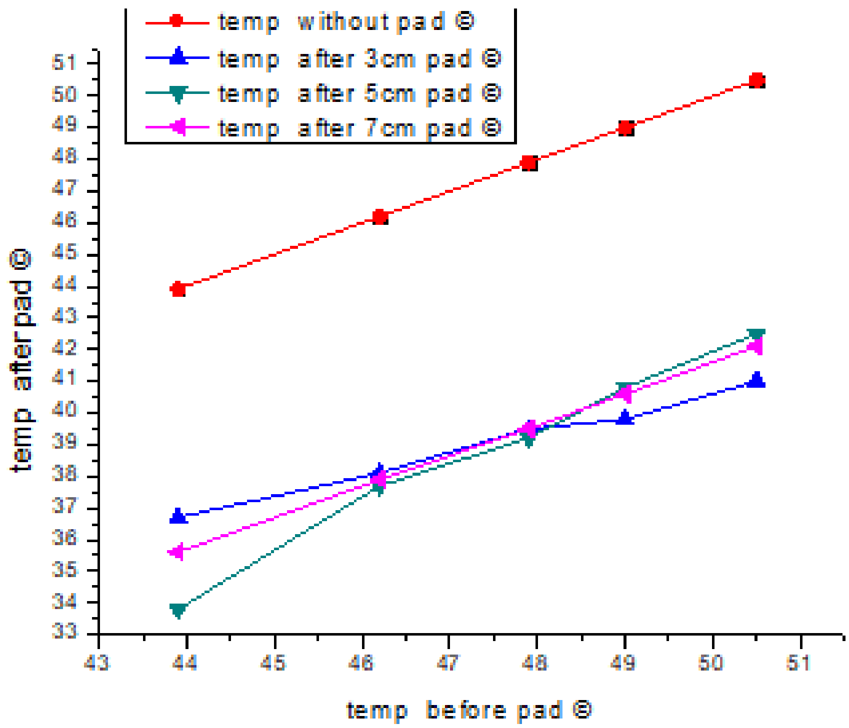


Figure (5 -35) Effect of a different thickness of the pad on the outside temperature at 100 liters/h.

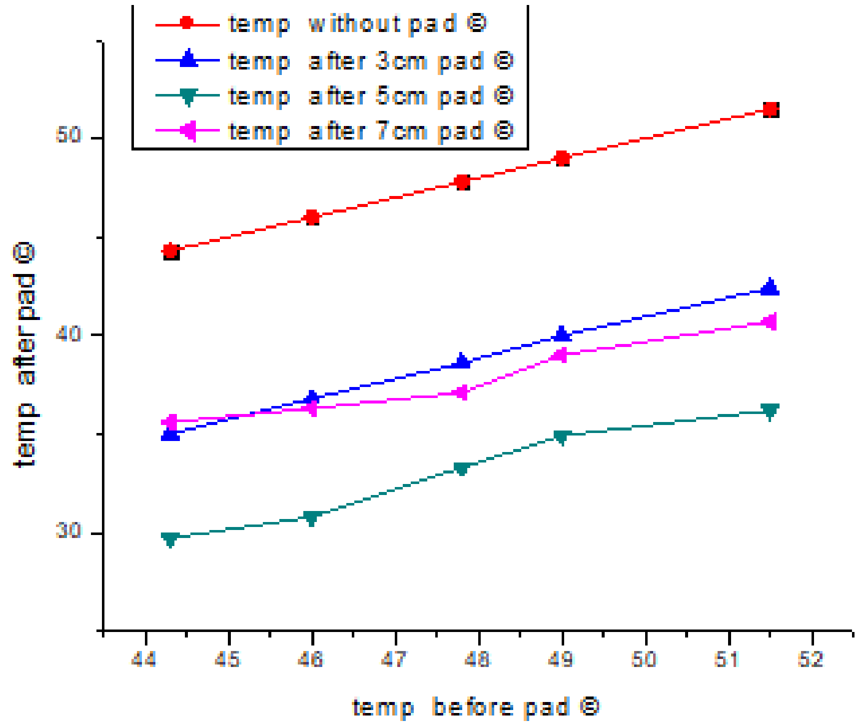


Figure (5-36) Effect of a different thickness of the pad on the outside temperature at 125 liters/h.

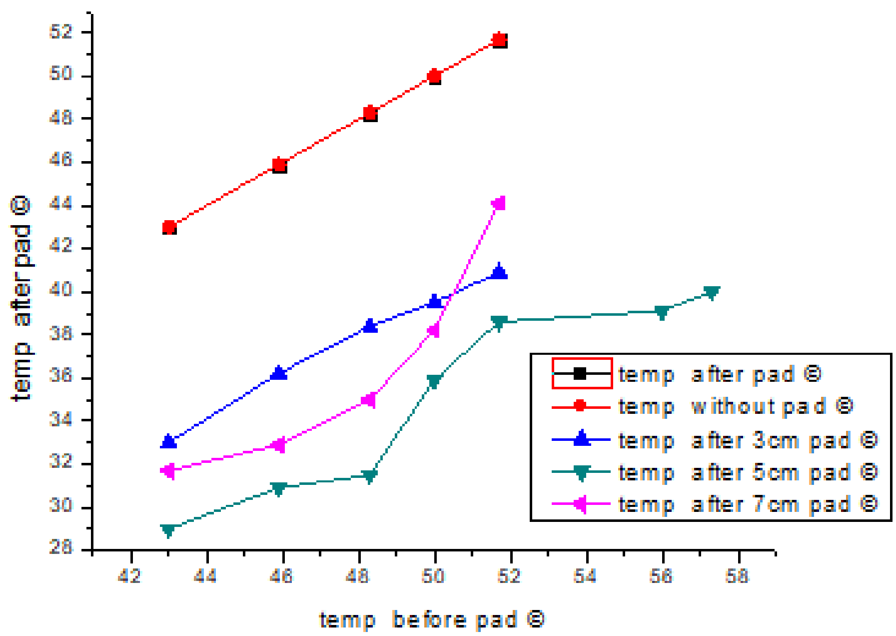


Figure (5-37) Effect of a different thickness of the pad on the outside temperature at 150 liter /h

Figure (5-38, 5-39, 5-40) shows the effect of the thickness of the pad on the energy of the evaporative condenser and at a variable volume flow (100, 125, 150) Liter/h. Where it turns out that the largest energy of the condenser in all the fluxes was at the thickness of the pad 5 cm, while it was the lowest energy at the thickness of the pad of 3 cm at the same volumetric flow.

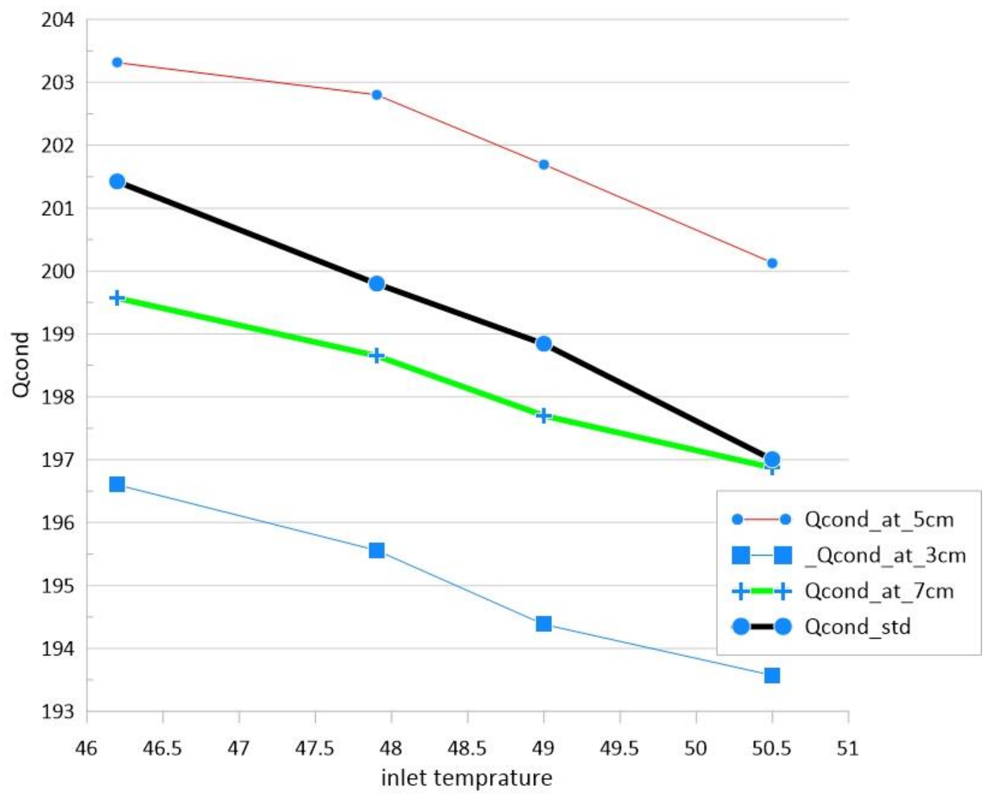


Figure (5 -38) Effect of the air inlet temperature on condenser temperature for unit with evaporator condenser at 100 Liters/h.

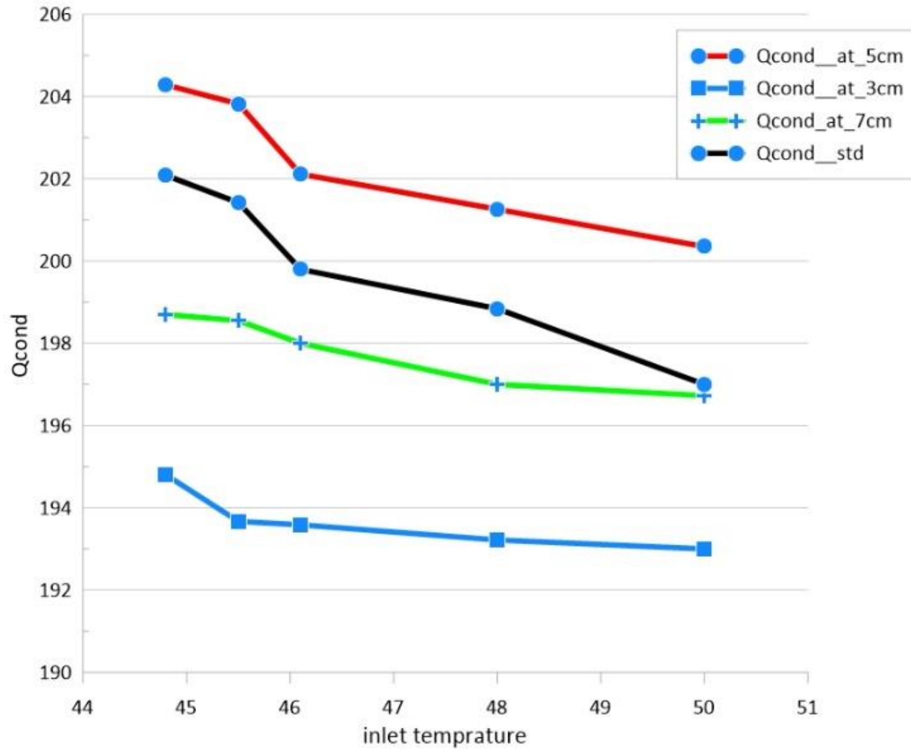


Figure (5 -39) Effect of the air inlet temperature on condenser temperature for unit with evaporator condenser at 125 Liters/h

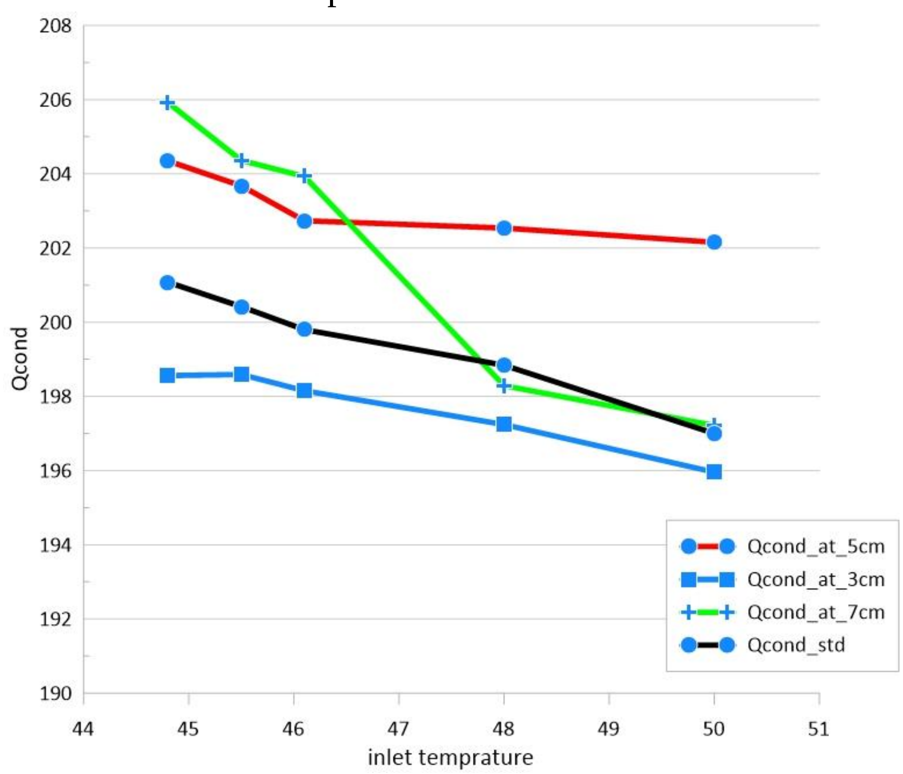


Figure (5 -40) Effect of the air inlet temperature on condenser temperature for unit with evaporator condenser at 150 Liters/h

5-3 Theoretical results obtained from EES

Figure (5-41) shows the variables of the unit with an evaporative condenser with a thickness of 3 cm and a volumetric water flow of 100 liter/h at a temperature of 46.2. Where the COP and the work of the compressor was calculated. It was also compared with the previous results and an estimated error rate (0.3%) was obtained.

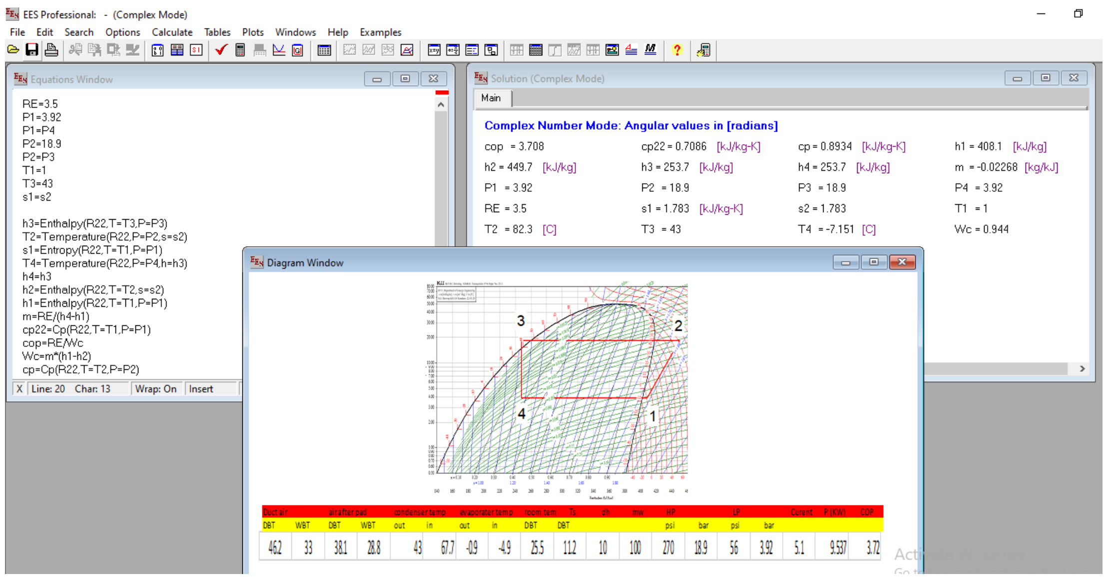


Figure (5-41) Results obtained from EES at 3 cm and a volumetric water flow of 100 liter/h.

Figure (5-42) shows the parameters of a unit with an evaporative condenser with a pad thickness of 5 cm and a volumetric water flow of 150 liters/h at a temperature of 48.5 °C. The COP and compressor work were calculated. It was also compared with previous results and an estimated error rate (%0.6) was obtained.

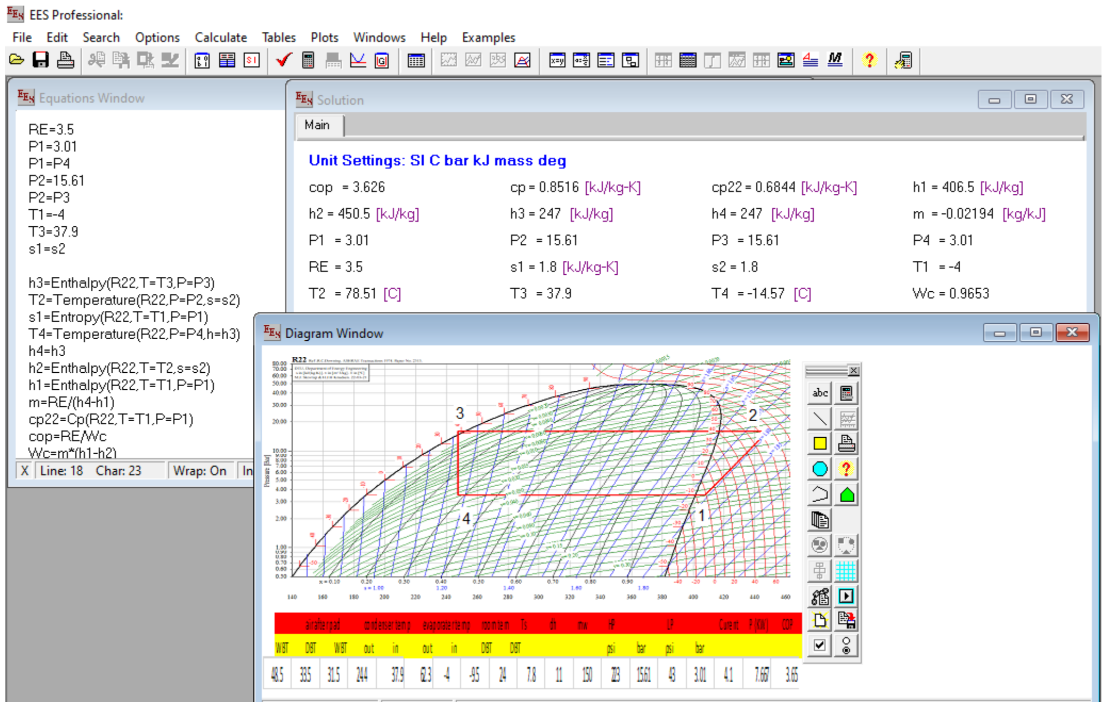


Figure (5-42) Results obtained from EES at 5 cm and a volumetric water flow of 150 liter/h.

Figure (5-43) shows the parameters of a unit with an evaporative condenser with a thickness of 7 cm and a volumetric water flow of 150 liters/h at a temperature of 49.1 ° C. The COP and compressor work were calculated. It was also compared with previous results and an estimated error rate (%3.1) was obtained.

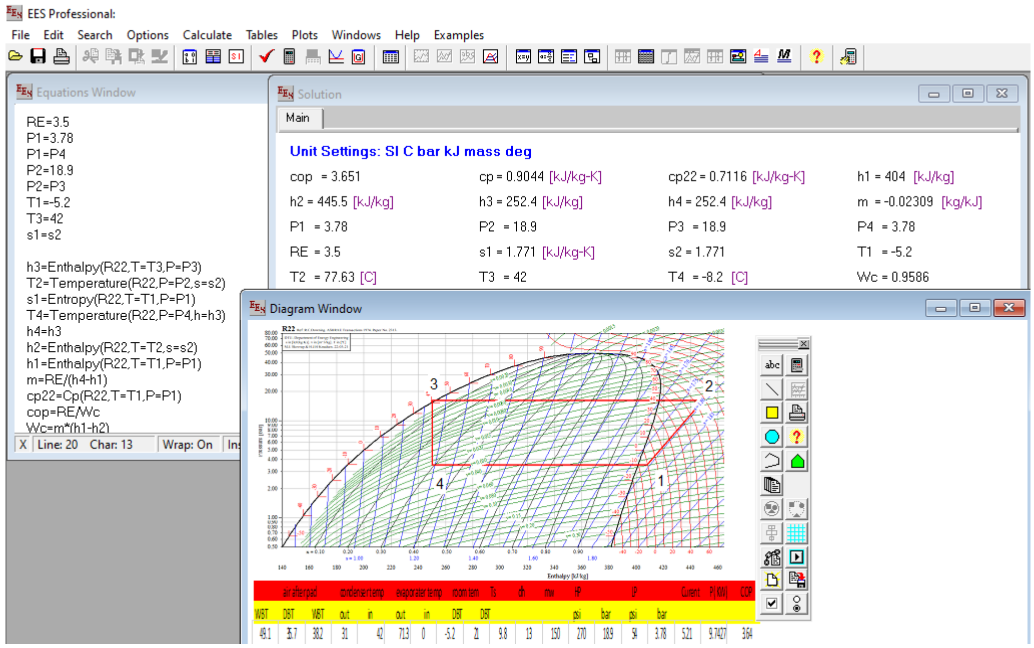


Figure (5-43) Results obtained from EES at 7 cm and a volumetric water flow of 150 liter/h.

Figure (5-44) shows the parameters of a standard unit (without pad) at a temperature of 38.8 ° C. The performance factor and compressor work were calculated. It was also compared with previous results and an estimated error rate (%3.3) was obtained.

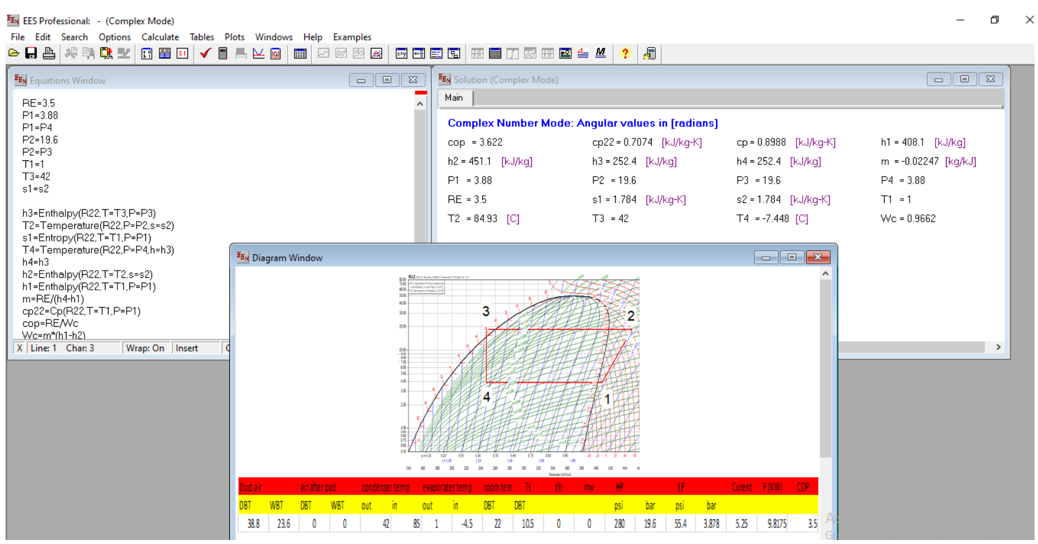


Figure (5-44) Results obtained from EES at standard unit (without pad).

Figure (5-45) shows a comparison between the COP of units with an evaporative condenser with a thickness of (3, 5, 7) cm and the basic unit with the compressor working. The drawing shows that the best COP of the unit when using the evaporative condenser (5) cm.

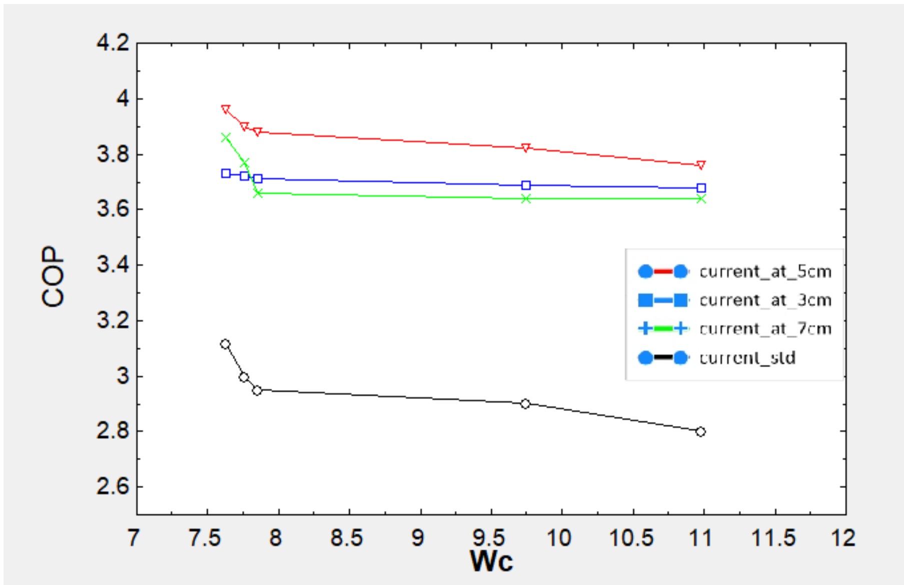


Figure (5-45) comparison between the performance coefficient of units with an evaporative condenser with a thickness of (3, 5, 7) cm and the basic unit with the compressor working.

5-4 Comparison of previous researchers

This chapter aims to show the most important comparisons with previous researchers who used the evaporative condenser. The comparison was made in terms of studying all the parameters that affect the work and efficiency of the evaporative condenser and showing the most important results obtained through these comparisons:

5-4-1 Comparison in terms of temperature.

1- Wang et al. 2014 [46] He conducted practical experiments with the evaporative condenser at dry temperatures (23.8, 27.8, 33.1, 43.8, 46) °C. The use of the evaporative condenser at these temperatures increased the COP from 6.1% to 18%, and the compressor energy savings up to 14.3%. The best results of the system were at a dry temperature of 33.1 °C. While the results obtained from the practical results of this study were compared and at temperatures (43.9, 46.2, 47.9, 49, 50.5) °C and at the lowest volumetric flow of water (100 liter / h) and the lowest thickness of the pad, i.e. at (3 cm), then we find that a better COP was obtained, which represents the percentage increase (20%). as show in table(5-1).

Table(5-1)

Temperature ℃	Increase in COP of ref [46]	Increase in COP of experimental results	Error %
43.8	17%	18%	5.9%
46	18%	20%	11%

Figure (5-46) Comparison of COP with the ref [46]

5-4-2 Comparison in terms of air velocity.

Taliv 2019 [47] The researcher conducted practical experiments when using the direct evaporative condenser at a temperature of (29) °C and an air speed of (4.5 m/s). The results showed that COP increased by 10.6%, while the increase in COP was 24% at a temperature of 44°C and an air velocity of 4.5m/s. Using an indirect evaporative condenser with a pad thickness of 3 cm and a volumetric water flow of 100 Liter/h. Note that these are the least experimental results obtained.

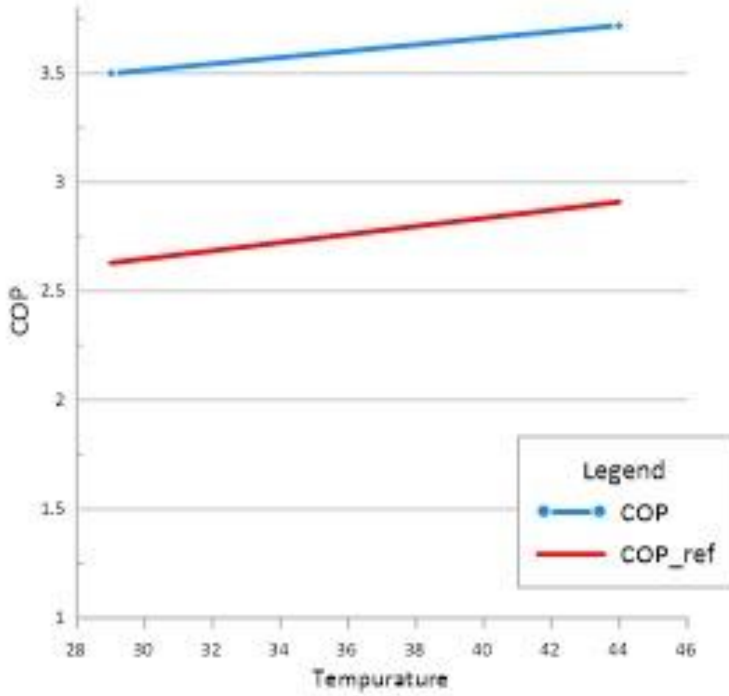


Figure (5-48) Comparison of experimental results with the ref [47]

5-4-3 Comparison in terms of pad thickness.

Martínez 2016 [57].The researcher used an indirect evaporative condenser using a pad with a thickness of (5, 10, 15) cm .Approximately maximum benefit was obtained for a 5 cm cooling pad at a temperature of 39°C with a variable relative humidity of (42%, 51%, 64%). The increase in the COP was 16.5% for thickness of 5 cm, while the increase was (10.6% and 9.0%) for pad thickness (10,15) cm, respectively, at relative humidity of 42%. While the increase for the COP is equal to be 9.2% for all pad thicknesses at a relative humidity of 51%, and the percentage increase is 9.6% for all pad thicknesses at 64% relative humidity. While the highest results were obtained when we used a pad with a thickness of (5 cm) at with a humidity of up to 35%, where the increase in the COP was (17.6%).as show in table(5-2).

Table(5-2)

Pad thickness	Increase in COP of ref [57]	Increase in COP of experimental results	Error %
5cm	16.5%	17.6%	5.9%

5-4-4 Comparison in terms of water volume flow rate.

Yang. 2020 [19] The direct evaporative condenser was used in terms of controlling the water flow rate between (2.5 - 25) liters / h. This improvement led to an increase in the COP from 6% to about 9% at a temperature of 40 ° C and energy savings were achieved by 2.37% to 13.53%, while when using the evaporative condenser at the same temperature and at a volumetric flow of water 100 liter/h the increase in The COP reaches 18.6%, while the energy savings reach 16%.as show in Figure (5-50)

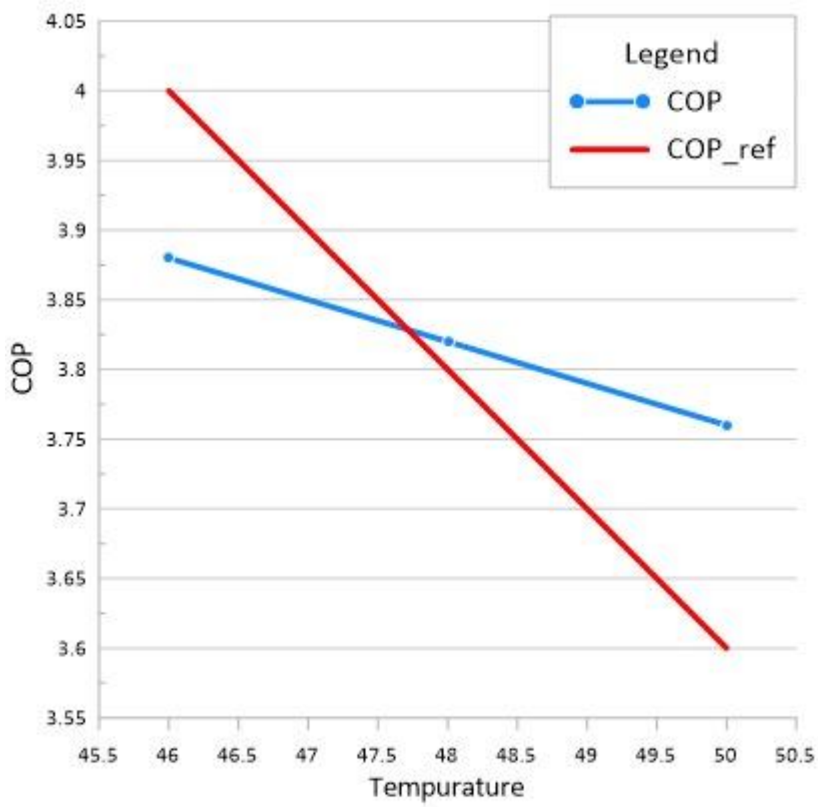


Figure (5-50) Comparison of practical results with the researcher [19]

5-5 Cost analysis

Cost analysis usually comes from the most important conclusions when any study works to develop or improve the work of any system. In this chapter, the additional costs will be prepared and studied when improving the basic unit and the extent of their impact in terms of energy consumption after the improvement.

5-6 Classified the Cost analysis

Cost analysis can be categorized into two main parts as follows:

5-6-1 Construction Costs

The construction costs consist of the costs of adding new materials and the costs of operational costs, as will be explained below:

5-6-1-1 Cost of new materials:

The pad used when using the indirect evaporative condenser, a pad of a certain thickness should be placed according to the study prepared to meet the required need. The cost of purchasing one pillow is $2.4. With dimensions sufficient to cover a separate cooling unit with a capacity of (3.5 kW), equivalent to (1 ton of refrigeration cooling).

The sprinklers used are a stream of water that contains holes of equal dimensions and diameters that work for a good distribution of water over the surface of the filling. These sprinklers cost $2.75 or can be created by the user himself.

The water pump was equipped with a submersible type with a small capacity that does not exceed the volumetric flow (170 liters / h) at a height of 1 meter. The cost of this pump ($3.4).

The pipes used for the purposes of transporting water were of the plastic type, with a diameter of 1/2 inch, and a length not exceeding 5 m (adding a compensation water line, including). The cost for these tubes was ($3.4).

A raft for water compensation is necessary to use floats for the compensation line to prevent waste of water. The cost of this raft is $2.75. A plastic water tank with a capacity of 25 liters was used. The cost of this tank is ($3.4).
A plastic or metal Water regulating valve can be used for this purpose.

The cost of the valve ($1.25)

Total cost of new materials

Total construction costs ($19.35)

5-6-2 Operational costs.

In addition to construction costs, there are also construction costs worth mentioning, such as the cost of running a water pump

Since the water pump is of an electric type, it is necessary to indicate the consumption of this part of the power and add it to the consumption of the unit. The electrical power consumption of this pump is 0.4 amps, which is equivalent to 0.088 watts. The global cost of watt-hours is $0.138. On this basis, the operating cost of the pump is equivalent to $0.0121 per hour, and it is $8.74 per month.

5-6-3 Energy consumption analysis.

Energy consumption is one of the disadvantages of cooling systems, especially in the summer season at high temperatures. Energy consumption can be classified as in the paragraphs below.

5-6-3-1 Energy consumption of the unit without the evaporative condenser

The average power consumption by the unit without the evaporative condenser is 1.21 W

At a cost of $120 per year at temperatures ranging (44.8) degrees Celsius.

5-6-3-2 Energy consumption with the unit of evaporative condenser

The energy consumption with the use of the evaporative condenser in all the studied cases, as in Table (5-1) below.

Table (5-1) Energy consumption

Average temperature	Watt	Pad thickness	Vw	Energy consumption at year ($)
47.5	1.1264	3	100	811.008
47.7	1.1572	3	125	833.184
47.8	1.0406	3	150	749.232
45.3	1.0516	5	100	757.152
47.44	1.056	5	125	760.32
54.22	0.9394	5	150	676.368
47.5	1.1308	7	100	814.176
46.9	1.1308	7	125	814.176
46.3	1.034	7	150	744.48

Chapter Six

Conclusions and Recommendations

Conclusions and Recommendations

6-1 Conclusions

In this practical study and after obtaining and analyzing the results, we find that there are many conclusions that have been obtained that can be described in this chapter, which are as follows:

1- The coefficient of performance for air conditioning units increases when evaporative condensers are used instead of air-cooled condensers.
2- Energy consumption is reduced so that it is more energy-saving for air conditioning units when evaporative condensers are used instead of air-cooled condensers.
3- The percentage of performance coefficients increases for air conditioning units when using evaporative condensers with increasing temperatures.
4- The coefficient of performance increases when the volumetric flow of water is increased when the pad is 3 cm, while it decreases when using the pad (5 & 7) cm.
5- The performance coefficient increases significantly when the thickness of the pad is increased from 3 cm to 5 cm, while the increase is little when using a bandage (7) cm.
6- The best performance coefficient was obtained when using a fill thickness of 5 cm at a rate of 25.2% at a volumetric flow of 100 Liter/h.
7- The best energy savings were obtained when using a filling thickness of 5 cm and a rate of 22.4% at a volumetric flow of 150 Liter/h.
8- When using an evaporative condenser with a thickness of 5 cm and a volumetric flow of 150 liters / h, the unit was able to avoid auto shutdown until the temperature reached 57.3 °C.
9- The temperature of the recycled water is lower than the outside temperature, which gives better results when re-pumping the pad wetting process.

6-2 Recommendations.

Through the practical experiments that were carried out through the use of the evaporative condenser on the air conditioning unit, we recommend the following:

1- Using the indirect evaporative condenser instead of the direct evaporative condenser, due to less water depletion, in addition to the absence of salt deposits on the surface of the condenser, which leads to damage over time.
2- Since the cost of setting up the evaporative condenser does not exceed $20, while it gives better results and continuous work for the system even at temperatures up to 57 °C, it is recommended to use the evaporative condenser.
3- The use of an evaporative condenser with a cushion thickness of 5 cm and a volumetric flow of 100 liters / hour. Because it is more energy-saving and does not require a large pump for water.
4- In the event that the internal load is large and variable, it is recommended to use an evaporative condenser with a pillow thickness of 5 cm and a volumetric flow of 150 liters / hour, as it has the highest performance coefficients.

5- It is suggested to study the distance between the condenser of the air conditioning unit and the pad.

6- Using different types of pad to study their effect on energy saving and COP.

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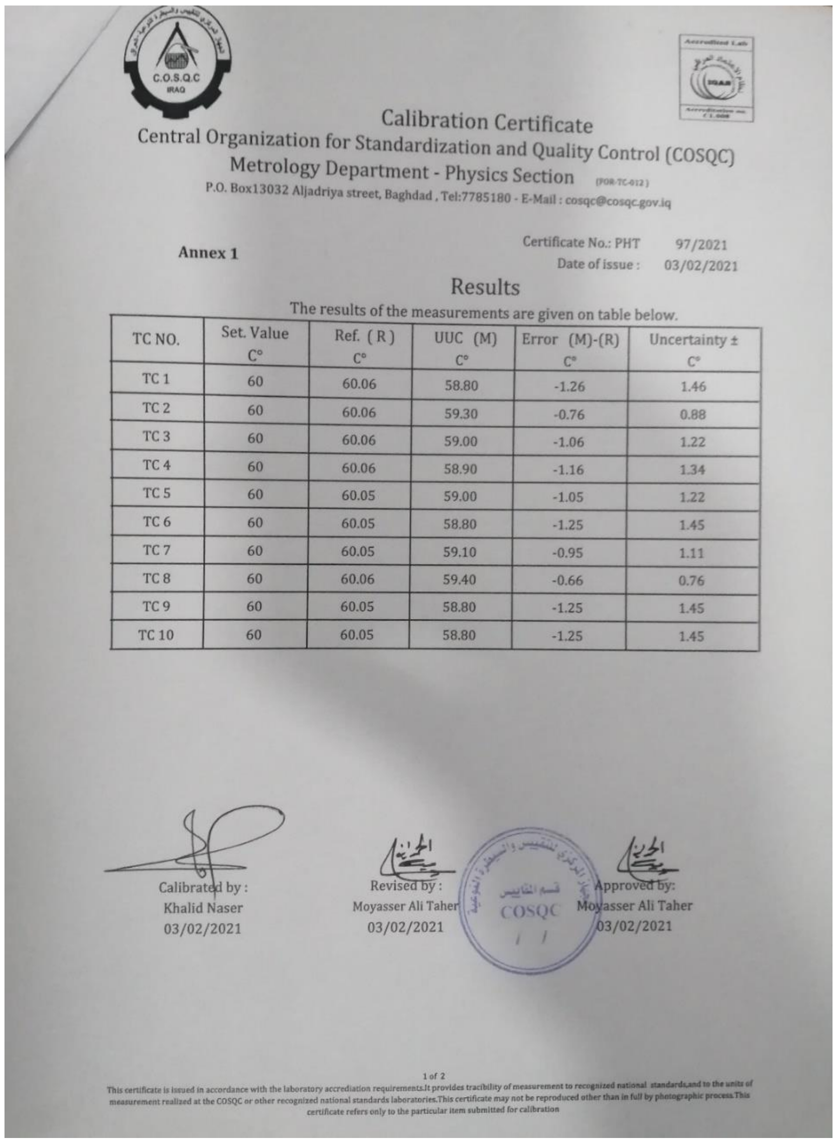
Appendices: (A) measuring instrument calibration

Appendix- A-1 Thermocouples certificate

This appendix represents the test certificate for temperature sensors type (K) by Central Organization for Standardization and Quality Control (COSQC).



C.O.S.Q.C
IRAQ

Calibration Certificate
Central Organization for Standardization and Quality Control (COSQC)
Metrology Department - Physics Section (FOR-TC-012)
P.O. Box13032 Aljadriya street, Baghdad , Tel:7785180 - E-Mail : cosqc@cosqc.gov.iq

Annex 1

Certificate No.: PHT 97/2021
Date of issue : 03/02/2021

Results

The results of the measurements are given on table below.

TC NO.	Set. Value C°	Ref. (R) C°	UUC (M) C°	Error (M)-(R) C°	Uncertainty ± C°
TC 1	60	60.06	58.80	-1.26	1.46
TC 2	60	60.06	59.30	-0.76	0.88
TC 3	60	60.06	59.00	-1.06	1.22
TC 4	60	60.06	58.90	-1.16	1.34
TC 5	60	60.05	59.00	-1.05	1.22
TC 6	60	60.05	58.80	-1.25	1.45
TC 7	60	60.05	59.10	-0.95	1.11
TC 8	60	60.06	59.40	-0.66	0.76
TC 9	60	60.05	58.80	-1.25	1.45
TC 10	60	60.05	58.80	-1.25	1.45

Calibrated by : Khalid Naser 03/02/2021

Revised by : Moyasser Ali Taher 03/02/2021

Approved by: Moyasser Ali Taher 03/02/2021

COSQC

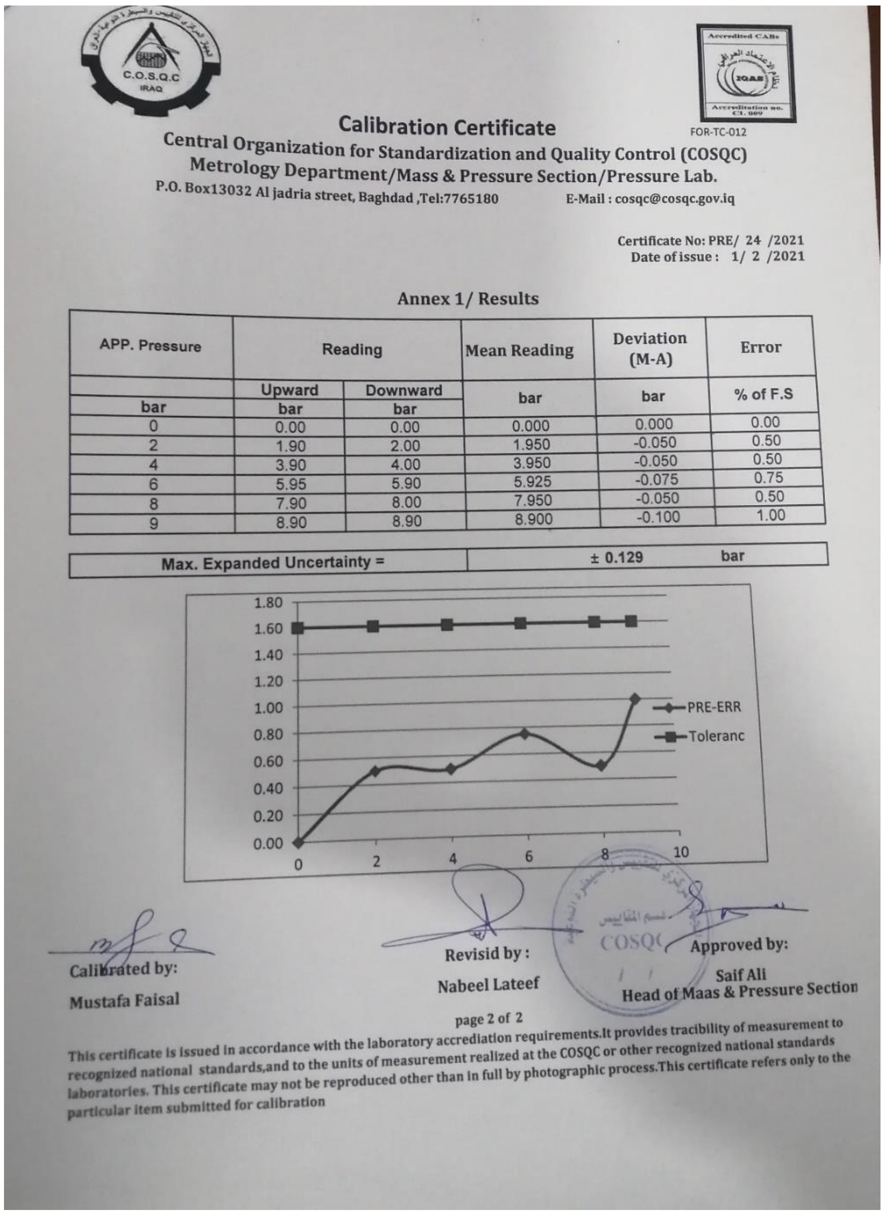
1 of 2

This certificate is issued in accordance with the laboratory accrediation requirements.It provides tracibility of measurement to recognized national standards,and to the units of measurement realized at the COSQC or other recognized national standards laboratories.This certificate may not be reproduced other than in full by photographic process.This certificate refers only to the particular item submitted for calibration

Figure (A-1) Thermocouples certificate

Appendix- A-2: Pressure gauges certificate

This appendix represents a test certificate for pressure gauges by the Central Organization for Standardization and Quality Control (COSQC).



C.O.S.Q.C
IRAQ

Accredited CABs
IQAS
Accreditation no. CL 009

Calibration Certificate FOR-TC-012

Central Organization for Standardization and Quality Control (COSQC)
Metrology Department/Mass & Pressure Section/Pressure Lab.
P.O. Box13032 Al jadria street, Baghdad ,Tel:7765180 E-Mail : cosqc@cosqc.gov.iq

Certificate No: PRE/ 24 /2021
Date of issue : 1/ 2 /2021

Annex 1/ Results

APP. Pressure	Reading		Mean Reading	Deviation (M-A)	Error
	Upward	Downward	bar	bar	% of F.S
bar	bar	bar			
0	0.00	0.00	0.000	0.000	0.00
2	1.90	2.00	1.950	-0.050	0.50
4	3.90	4.00	3.950	-0.050	0.50
6	5.95	5.90	5.925	-0.075	0.75
8	7.90	8.00	7.950	-0.050	0.50
9	8.90	8.90	8.900	-0.100	1.00

Max. Expanded Uncertainty =	± 0.129 bar

Calibrated by:
Mustafa Faisal

Revisid by :
Nabeel Lateef

Approved by:
Saif Ali
Head of Maas & Pressure Section

page 2 of 2

This certificate is issued in accordance with the laboratory accrediation requirements.It provides tracibility of measurement to recognized national standards,and to the units of measurement realized at the COSQC or other recognized national standards laboratories. This certificate may not be reproduced other than in full by photographic process.This certificate refers only to the particular item submitted for calibration

Figure (A-2) Pressure gauges certificate

Appendix- A-3: Air flow rate certificate

This accessory represents a test certificate for an air velocity meter from the manufacturer

Parameter

Functions	Range	Resolution	Accuracy
Wind Speed	0~30m/s	0.1m/s	±5%rdg+0.5
Temperature	-10~50℃	0.1℃	±2℃
	14~122℉	0.2℉	±4℉
Wind Scale	Level 0~12	1	±1
Sampling Rate			0.5s
Overload Indication	>45m/s		OL
MAX/AVG			MAX/AVG
Data Hold			HOLD
LCD Backlight			Yes
Auto Power Off			5min
Low Battery Indication			3.0~3.5V
Battery			4.5V
Current Consumption	Working	mA	≤25mA
	Power off	uA	≤10uA
Work Environment	Temperature		0~40℃
	Humidity		≤80%RH
Storage Environment	Temperature		-20~60℃
	Humidity		≤75%RH

Figure (A-3) Air flow rate certificate

Appendix. B: Measurements table

Table (B-1) below shows the results obtained when using the natural air-conditioning system without any addition with a constant air velocity not exceeding 4.5 m/s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	out	in	Std		
38.8	23.6	Not used	Not used	46	85	0	3.5	9.8175
40.1	24.9	0	0	49	90	0	3.36	9.8175
42.5	27.3	0	0	52	100	0	3.14	9.911
44.1	28.9	0	0	55	110	0	3	10.1915
48.1	32.9	0	0	56	115	0	2.95	10.4533
49.2	34	0	0	58	117	0	2.9	10.659
50	34.8	0	0	60	120	0	2.8	11.22
54	39.3	0	0	65	125	0	cutoff	cutoff

Table (B-2) below shows the results obtained when using the natural air conditioning system with the addition of an evaporative condenser with a thickness of 3 cm, a quantity of water 100 liters / h, and a constant air speed not exceeding 4.5 m/s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	out	in			
43.9	30.4	36.7	27.2	42.3	67.2	100	3.73	9.2004
46.2	33	38.1	28.8	43	67.7	100	3.71	9.537
47.9	34.6	39.5	30.1	43.3	68.2	100	3.73	9.6679
49	34	39.8	30.5	43.3	68.6	100	3.69	9.724
50.5	37	41	32	43.5	69.5	100	3.68	9.724

Table (B-3) below shows the results obtained when using the natural air conditioning system with the addition of an evaporative condenser with a filling thickness of 5 cm, a water quantity of 100 liters / h and a constant air speed not exceeding 4.5 m / s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	Out	IN			
40.6	25.5	32.9	26.4	38.4	67.6	100	3.96	8.228
42.9	27.8	33.8	27.3	38.5	68.7	100	3.9	8.789
45.5	30.4	37.7	31.2	38.8	69.2	100	3.88	8.976
47.1	32	39.2	32.7	39.2	69.2	100	3.82	9.2004
50.4	35.3	42.5	36	39.7	70.2	100	3.76	9.4809

Table (B-4) below shows the results obtained when using the natural air conditioning system with the addition of an evaporative condenser with a filling thickness of 7 cm, a water quantity of 100 liters / h and a constant air speed not exceeding 4.5 m / s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	out	in			
43.9	30.4	35.6	27.2	40.5	68.2	100	3.86	8.8825
46.2	33	37.9	28.8	40.7	68.7	100	3.77	9.2565
47.9	34.6	39.5	30.1	43.3	68.5	100	3.66	9.724
49	34	40.6	30.5	43.5	68.6	100	3.64	9.911
50.5	37	42.1	32	43.5	69.5	100	3.64	10.285

Table (B-5) shows the results obtained at a filling thickness of 3 cm, a water volume of 125 liters / h, and an air speed of 4.5 m/s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	OUT	IN			
44.3	33.5	35	24.8	42.9	67.2	125	3.72	9.537
46	34.6	36.8	26.7	43.3	68.2	125	3.74	9.724
47.8	9.2	38.6	29.4	43.7	68.6	125	3.72	9.8175
49	34	40	31.5	44.3	69.1	125	3.68	9.9484
51.5	38	42.4	33	44.7	69.4	125	3.69	10.1541

Table (B-6) shows the results obtained at a filling thickness of 5 cm, a water volume of 125 liters / h, and an air speed of 4.5 m/s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	OUT	IN			
44.2	29	29.7	22.8	40.1	70.2	**125**	3.74	8.8825
45.1	29.9	30.8	23.9	40.2	70.6	**125**	3.74	8.976
47.6	32.4	33.3	26.4	40	70.9	**125**	3.75	8.976
49.5	34.3	34.9	28	40.2	70.7	**125**	3.74	8.976
50.8	35.6	36.2	29.3	40.3	70.3	**125**	**3.74**	9.0695

Table (B-7) shows the results obtained at a filling thickness of 7 cm, a water volume of 125 liters / h, and an air speed of 4.5 m/s.

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	OUT	IN			
44.8	31.4	35.6	25.8	40.7	68.2	**125**	3.83	8.976
45.5	32.1	36.3	26.5	40.9	68.6	**125**	3.82	9.4435
46.1	32.7	37.1	27.3	42.7	69.8	**125**	3.71	9.537
48	34.6	39	29.2	43.2	70.2	**125**	3.65	9.7988
50.8	35.6	36.2	29.3	40.3	70.3	**125**	3.62	10.285

Table (B-8) shows the results obtained when using the evaporative condenser according to the parameters (dry bulb temperature, wet bulb temperature, air velocity 4.5 m/s, water volume flow rate 150 liters / h, filling thickness (3 cm).

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	OUT	IN			
43	**28.1**	**33**	**23.4**	**40.2**	**67.2**	**150**	**3.9**	**8.3402**
45.9	**30.7**	**36.2**	**24**	**40.8**	**68.2**	**150**	**3.82**	**8.4524**
48.3	**33.5**	**38.4**	**28.8**	**41.3**	**68.6**	**150**	**3.75**	**8.789**
50	**35**	**39.5**	**30.7**	**41.7**	**69**	**150**	**3.69**	**9.0695**
51.7	**35.9**	**40.9**	**32**	**42.2**	**69.3**	**150**	**3.64**	**9.5183**

Table (B-9) shows the results obtained when using the evaporative condenser according to the parameters (dry bulb temperature, wet bulb temperature, air velocity 4.5 m/s, water volume flow rate 150 liters / h, filling thickness (5 cm).

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	OUT	IN			
48.5	33.5	31.5	24.4	37.9	62.3	150	3.64	7.667
53.1	38.1	35.9	28.8	38.7	63.1	150	3.62	7.854
55.8	40.8	38.6	31.5	38.8	63.2	150	3.62	7.854
56.4	41.4	39.1	32	39	63.4	150	3.62	8.228
57.3	42.3	40	32.9	39.2	63.4	150	3.62	8.3215

Table (B-10) shows the results obtained when using the evaporative condenser according to the parameters (dry bulb temperature, wet bulb temperature, air velocity 4.5 m/s, water volume flow rate 150 liters / h, filling thickness 7(cm).

ambiant air		air after pad		condenser temp		VFR	COP	Q (KW)
DBT	WBT	DBT	WBT	OUT	IN			
41	27.6	30.2	20.4	37.2	65.8	150	3.68	7.6296
42.5	29.1	31.7	21.9	37.7	66.2	150	3.61	7.7605
43.7	30.3	32.9	23.1	38.9	66	150	3.61	7.854
49.1	35.7	38.2	31	42	71.3	150	3.64	9.7427
55	41.6	44.1	34.2	43.2	73.2	150	3.56	10.9769

Figure (B-1) shows the basic cycle before adding the evaporative condenser at a temperature of 48 °C and after adding the evaporative condenser at the same temperature and with an amount of water 125 liters / h. The black color indicates the basic cycle without any addition, as it was shown that the cycle is the least efficient and the highest in terms of pressure and temperatures inside the condenser and evaporator.

The green color indicates the use of an evaporative condenser with a thickness of 3 cm. Where there is a slight improvement over the basic course.

The red color indicates the use of an evaporative condenser with a thickness of 7 cm. Where it shows that the improvement is higher than the previous two cases (the basic cycle and when the thickness of the pad is 3 cm).

The blue color represents the basic cycle with the use of an evaporative condenser with a thickness of 5 cm. Where the diagram shows that this cycle is the most efficient with the least pressure inside the condenser and evaporator, which results in the largest savings in the energy spent, as has been proven in Table (B-6) above.

The figure (B-2) shows that the highest performance of the system is with the use of the evaporative condenser with a thickness of 5 cm, which is colored green. The lowest pressures were recorded with lower temperatures inside the condenser and evaporator. And, then, followed by the cycle with the evaporative condenser with a thickness of 7 cm, which is in blue. While the cycle with the evaporative condenser with a thickness of 3 cm, which is in red.

The Figure (B-3) shows all cycles under the same operating conditions. It is easy to show the changes in the system before and after the improvement, as well as which systems are the best when using different thicknesses of pads.

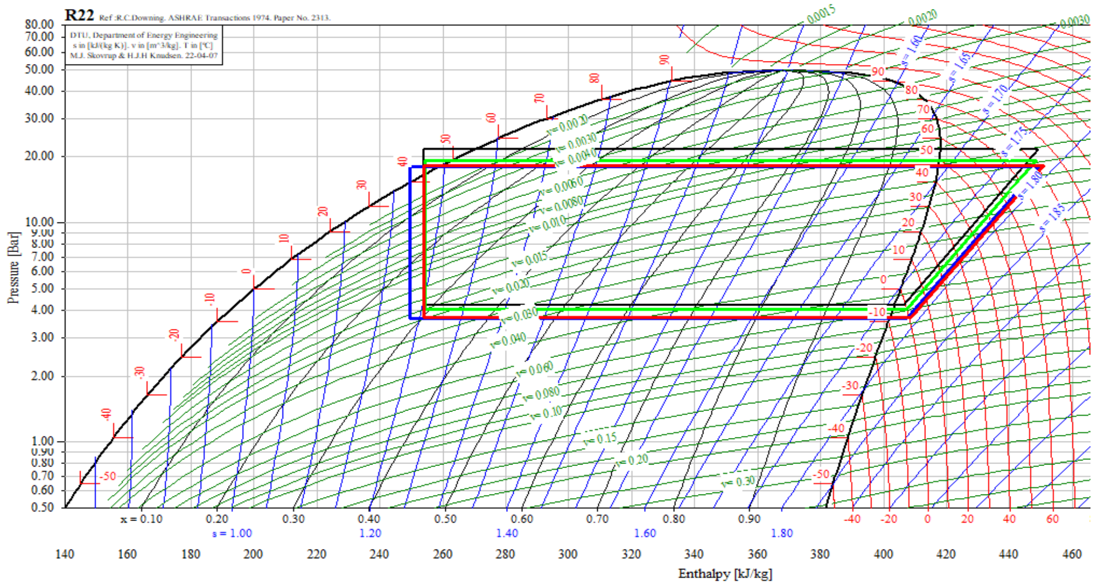


Figure (B-1) P-h diagrams for 3cm, 5cm and 7 cm pad thickness with standard cycle at water volume flow rate 125 liters / h.

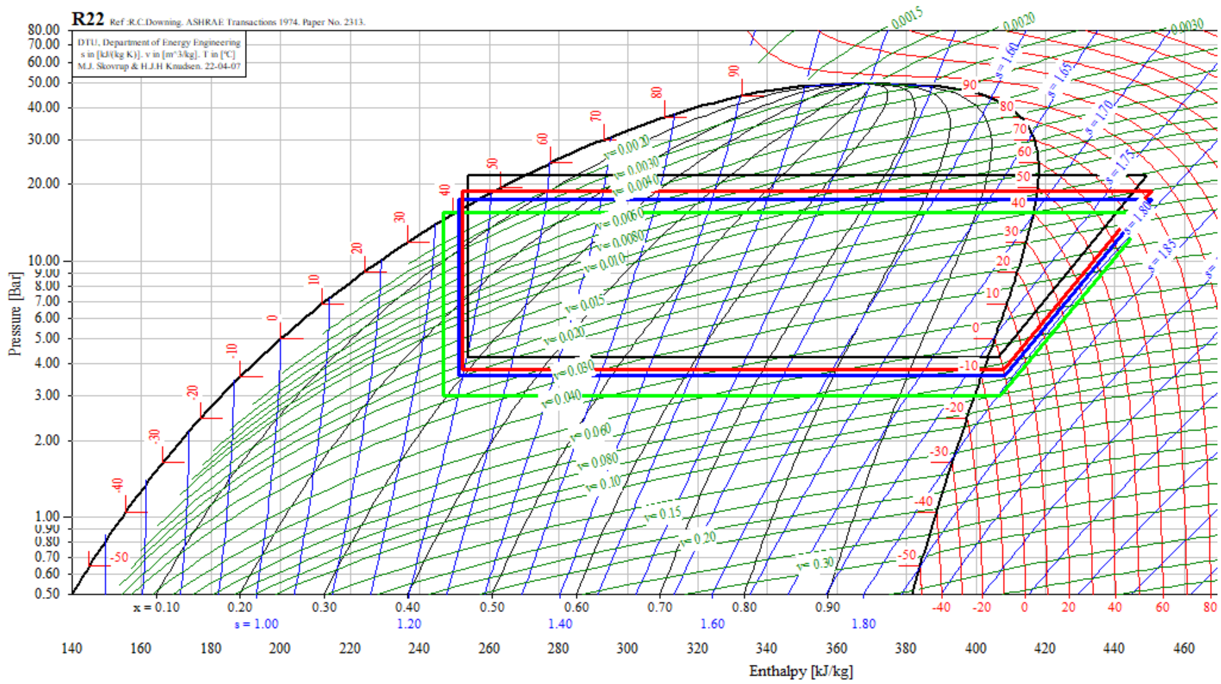


Figure (B-2) P-h diagrams for 3cm, 5cm and 7 cm pad thickness with standard cycle

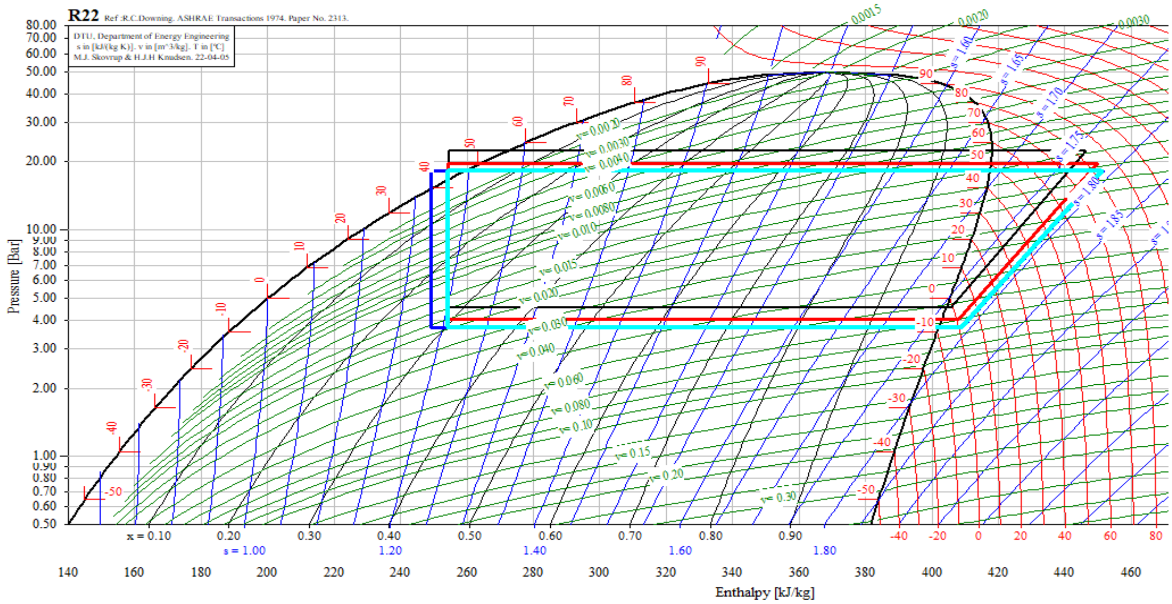


Figure (B-3) Comparison of P-h diagrams for R22 between 3cm, 5cm and 7 cm pad thickness with standard cycle

الخلاصة

من أهم العوائق في استخدام وحدات التبريد وتكييف الهواء ارتفاع استهلاكها للطاقة على مدار شهور السنة. لكن في مواسم الصيف ، وعندما تصل درجة الحرارة إلى أكثر من 40 درجة مئوية ، تستنزف هذه الوحدات كمية أكبر من الطاقة في بقية الفصول. بينما تنخفض معاملات هذه الوحدات بشكل ملحوظ أيضًا في فصل الصيف.

تم استخدام وحدة تكييف سبليت بسعة 1 طن في الجزء العملي. كما تم استخدام وسادة من السليلوز بسماكات مختلفة (3.5 ، 7) سم لتبريد الهواء المار خلال المكثف بمعدل تدفق ماء (100 ، 125 ، 150) لتر / ساعة.

في هذه الدراسة تمت دراسة العديد من التجارب العملية والتي أدت بدورها إلى زيادة متغيرات الأداء وكذلك توفير الطاقة عند استخدام المكثف التبخيري غير المباشر. حيث تم الحصول على زيادة في معامل الأداء بنسبة 21.8٪ عند استخدام مكثف تبخيري بسمك وسادة 3 سم وتدفق ماء حجمي 150 لتر / ساعة مع توفير في الطاقة بنسبة 14.2٪. بينما انخفضت الزيادة في معامل الأداء إلى 17.2٪ مع نسبة توفير في الطاقة بلغت 14.6 عند استخدام مكثف تبخيري بسمك وسادة 7 سم وتدفق ماء حجمي 100 لتر / ساعة. ثم تم تحقيق أفضل النتائج عند استخدام مكثف تبخيري بسمك وسادة 5 سم وتدفق ماء حجمي 100 لتر / ساعة ، للوصول إلى زيادة في معامل الأداء بنسبة 25.2٪ ، مع توفير طاقة بنسبة 13.2٪.

تحقيق عملي في الأداء وتوفير الطاقة لوحدة تكييف الهواء مع بمكثف تبريد تبخيري غير مباشر

اطروحة مقدمة الى قسم هندسة تقنيات ميكانيك القوى

كجزء من متطلبات نيل درجة الماجستير في هندسة الحراريات

تقدم بها

عبد الباسط ذاري يوسف حسن

اشراف

الدكتور باسل نوري مرزة　　　　الدكتور قاسم صالح مهدي

2022　　　　1444