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# Achieving optimum performance of a split air conditioner by using evaporative cooling

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## Abstract

Split cooling devices are widely used in different regions of the world. These devices work in high ambient temperatures during the summer months in many countries, such as Iraq, which increases electrical energy consumption and decreases the coefficient of performance. In addition, high temperatures expose the devices to damage, which means more maintenance and costs. This work investigates the potential of using a direct evaporative cooling system integrated with a split air conditioning unit to enhance the cooling performance and provide optimum operational conditions. The use of evaporative cooling is to reduce the condenser temperature of the outdoor split unit in the extremely hot summer. The mathematical development of the related equation is used to predict the cooling effectiveness. The climate conditions have been selected according to the Karbala city, Iraq, as it has a dry and hot climate, in which the temperatures may exceed 50°C. The results demonstrated the possibility of obtaining a higher coefficient of performance compared to the standard value of 2.96 by utilizing the evaporative cooling system. This in turn reduces the electrical energy consumption and makes the devices operate in very appropriate conditions, which prolongs the life of the devices and preserves them from damage.

**Keywords:** Split air conditioner; Evaporative cooling; Electrical energy consumption; Coefficient of performance

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## 1. Introduction

Two problems arise when using refrigeration and air conditioning devices in Iraq. The first is the electrical energy crisis and the attempt to reduce the use of electricity, and the second is the rise in climate temperatures, especially in the middle of summer, to be more than 50ºC [1]. In addition, another problem appears in different cities of Iraq, Karbala as an example, that have high-rise buildings close to each other and equipped with cooling devices, which is a greater rise in temperatures as a result of the expulsion of heat from the cooling devices on the lower floors and its impact on the cooling devices on the upper floors. Increasing the air temperature in this manner significantly raises the temperature and pressure of the refrigerant gas exiting the compressor. This, in turn, results in a higher pressure ratio, which leads the cooling unit to consume more electricity and may eventually cause the compressor to stop working permanently.

The method of cooling air by allowing water to evaporate is known as evaporative cooling, so it is highly suitable and highly effective in hot and dry climates. The two qualities of being hot and dry make evaporative cooling perfect, as its effectiveness increases with the increasing temperature and decreasing humidity, unlike what can be seen with mechanical cooling systems, which have a reduced efficiency when the outside air temperature increases [2,3], but direct evaporative cooling is insufficient to achieve the level of temperature comfort requirem-

## Nomenclature

$A$ – surface area at air-water interface, m$^2$
$c_{pu}$ – specific heat of the humid air, J/(kg K)
COP – coefficient of performance
$h_c$ – coefficient of convection heat transfer, W/(m$^2$ K)
$h_{LVS}$ – vapour specific enthalpy at surface temperature, J/kg
$h_m$ – coefficient of mass transfer, kg/(m$^2$ s)
$h_{VS}$ – vapour specific enthalpy at saturated surface temp., J/kg
$\dot{m}_a$ – mass flow rate of air, kg/s
Nu – Nusselt number
Pr – Prandtl number
$Q$ – heat flux applied, W/m$^2$
Re – Reynolds number
$R_{Le}$ – Lewis relationship
$T$ – bulk temperature, °C
$T_{cond}$– air temperature at the condenser, °C
$T_s$ – surface temperature, °C
$T_1$ – dry bulb temperature of the inlet air, °C
$T_2$ – dry bulb temperature of the outlet air, °C
$W$ – humidity ratio, kg$_w$/kg$_a$

### Greek symbols

$\varepsilon$ – cooling effectiveness
$\vartheta$ – volume of the used evaporative, m$^3$
$\mu$ – dynamic viscosity, Pa·s
$\rho_w$ – density, kg/m$^3$

### Subscripts

$a$ – air
$s$ – surface
$w$ – water

ents and relative humidity in very hot climates (such as the summer in Iraq), so it is fruitful to use evaporative cooling as pre-cooling to cool the condenser in split air conditions and thus obtain a high coefficient of performance and reduce the use of electrical energy and provide suitable working conditions.

Several researches have been conducted focusing on cooling the condenser of the split cooling device to enhance its performance. Hwang et al. [4] experimentally evaluated a 9 kW (2.6 tonnes) split heat pump system using an advanced styling of the evaporative-cooled condenser. It involves a tank of an acrylic box, 0.94 m wide, 0.66 m long and 0.66 m high. The tubes of the condenser were submerged in a cooling water tank to remove the heat from the condensing process. The rotating disks were partially submerged in the water bath as the air was blown over them. The disks transport a small layer of water from the bath to the air stream, where it evaporates. Compared to the baseline air-cooled results, the new design showed better performance, with a capacity increase of 1.8 to 8.1% and a COP increase of 11.1 to 21.6%. The disadvantages of Hwang's system are that it is too complicated, heavy and large. Goswami et al. [5] investigated the improvement of air-to-air vapour compression air conditioner performance by the application of indirect evaporative cooling. The system was modified with a media pad evaporative cooler, pump and source of water. The results show that an electric energy saving of twenty per cent was obtained by utilizing an evaporative-cooled air condenser.

Wang et al. [6] studied experimentally the possibility to increase the coefficient of performance of an air conditioning system using an evaporative cooling condenser. The data revealed an inverse relation between COP and the condenser inlet dry bulb temperature. The saturated temperature of the condenser increased from 2.4ºC to 6.6ºC by utilizing the evaporative cooling. It is also indicated that an increase in the mass flow rate of the refrigerant that passes through the evaporator results in the increase of COP from 6.1% to 18%. Elshiaty et al. [7] conducted practical experiments to evaluate the coefficient of performance and energy reduction in an air conditioning package unit. A comparison between two identical air conditioners was carried out, one was an ordinary air conditioner and the second was upgraded with a pump, water supply and nozzles that spray water onto the condenser, including optimized water consumption sprayers. The findings demonstrated that the coefficient of performance and the consumption of electrical power mainly rely on the surrounding conditions due to their effects on condensing temperature and pressure. The evaporative cooling enhanced COP by around 42.2% and reduced the electrical power consumption by 14.55%.

For an experimental evaluation of the energy saving utilizing different kinds of evaporative cooling systems, Chaktranond and Doungsong [8] retrofitted the condensing part in a split air conditioner unit with a water sprayer, cellulose corrugated pad, water source and a pump. The authors illustrated an increase in the consumption of electrical power energy of around 4% when the ambient temperature was raised by 1ºC. In addition, it was found that a decrease in power consumption of around 15% with an increase in COP by up to 48% due to large contact surface between air-stream and water. In regions where temperatures range from 50 ºC to 60 ºC, Alhamdo et al. [9] experimentally and theoretically investigated how to enhance condenser performance to improve the temperature of the evaporator outlet fluid. The result indicated that applying the spray water on the condenser is the best technique for improving the performance. The authors also presented a cost-benefit analysis related to the cost-benefit ratio, net present value, life cycle cost and payback period.

In Iraq, where temperatures can rise to 55ºC, Eidan et al. [10] investigated the impact of condenser evaporative pre-cooling on a tiny air conditioner of window type. They claimed that pre-cooling lowers the consumption of the peak power, and increases the working range to extremely high temperatures. It was also reported that the compressor can operate at a voltage of 16% less than 220 V by the use of evaporative pre-cooling.

To improve the cooling performance and reduce the consumption of electrical energy, this work attempts to explore the possibility of integrating a split air conditioning unit with a direct evaporative cooling system. A mathematical equation is developed to predict the cooling effectiveness which results in avoiding high costs of the experimental tests. The significance of this work lies in its contribution to offering ideal operating conditions for a split air conditioning unit that works in regions under an extremely hot and dry climate and/or installed within high-rise buildings such as in the case of Karbala city. As far as the authors are aware, no previous studies have addressed this particular issue.

## 2. Optimum operational conditions

There is an increasing interest in reducing electrical energy consumption as a result of global warming and energy crisis. Therefore, conserving energy and using environmentally friendly devices is very important, especially in hot regions with temperatures of 45−50ºC and long summers, where the use of electrical energy for cooling devices reaches 70% of the total energy used [6]. Increasing the outside air temperature increases the pressure and temperature of the refrigerant in the condenser unit, which in turn increases electrical energy consumption and reduces the cooling capacity of the cycle because, in a high-temperature environment, the refrigerant passing through the condenser might not completely condense, causing a mixture of liquid and vapour to enter the evaporator. Thus, the coefficient of performance of the cooling device decreases greatly as the outside air temperature rises [11]. The COP decreases by about 2−4% with each degree of increase in the temperature of the condenser [12,13]. The standard value of COP is 2.96 [14], which is at an outdoor air temperature approximately equal to 32.2ºC), and it is required to use evaporative cooling to cool the condenser when the outside air temperature is higher than 32.2ºC [15]. The addition of evaporative cooling to cool the condenser leads to lowering the temperature and pressure of the refrigerant in the condenser, thus increasing COP, reducing electrical energy consumption, increasing the duration of the cooling unit, and not stopping the cooling device, as the device is exposed to refrigerant pressures suitable for the compressor and obtaining high cooling capacities.

## 3. Equipment and system setup

### 3.1. Types of condensers

In heat pumps, condensers come in three different varieties: evaporative, water and air-cooled. The type used in conventional small tonnage is mainly air-cooled which needs a high air flow rate to enhance the performance. The bigger tonnage market uses water-cooled condensers, which rely on heat transfer from the refrigerant tube to the water flow.

The air-cooled condenser has a lower heat transfer coefficient compared to the water-cooled condenser. In the evaporative condensers, the evaporation of water into the air stream produces cooling. As a result, the water-cooled condensers require more water pumping and chemical treatment. Only sensible heat transfer is used in the air-cooled condenser, but both sensible and latent heat transfers are used in the evaporative condenser. Because of this, the evaporative condenser requires less airflow rate than an air-cooled condenser, allowing the present design to use a smaller fan and motor.

One of the main benefits of using an evaporative condenser over an air-cooled condenser is the lowered condensing temperature. More heat transfer is provided to the evaporative condenser by latent heat transfer, increasing its overall heat transfer coefficient over that cooled only by air. The condensing temperature of the evaporative condenser is lowered because of the smaller temperature differential caused by the improved overall heat transfer coefficient for a comparable quantity of transferred heat. Furthermore, rather than the dry-bulb temperature, the condensing temperature of this strategy is restricted by the air's wet-bulb temperature.

### 3.2. Performance of different refrigerants

R-410A typically operates in near-critical conditions when used in air conditioning systems at high outside temperatures. When the outside temperature rises, especially over 35ºC, the R-410A system performance can deteriorate more quickly than the R-22 system performance.

R-410A and R-22 air conditioners running at a high ambient temperature were compared by Payne et al. [16]. The identical condenser and evaporator heat exchangers were used to evaluate the two air conditioning systems. Normalized ratios were used to compare the R-410A system's capacity and COP to those of the R-22 system. At 35ºC, the capacities of the R-410A and R-22 systems matched, while at 27 ºC, the COPs matched. The authors reported that the ratio of the normalized capacity, R-22 against R-410A, declined from 1.05 to 0.90, and COP decreased from 1.05 to 0.80 when the ambient temperature was changed from 25ºC to 55ºC. The R-410A system appeared to be further susceptible to the rising outdoor temperature, according to the data.

In a thorough modelling study of comparing R-410A to R-22 systems, Rice [17] essentially verified the same findings. Thus, when subjected to an identical condenser evaporative precooling load, the R-22 apparatus experiences a less relative power reduction in comparison to the R-410A apparatus. Put differently, the refrigerant functions throughout a wide range of enthalpy changes in the two-phase area, which enhances the overall effectiveness of heat transfer from the condenser and allows it to reject more heat into the ambience at a fixed mass flow rate. As a result, precooling benefits energy savings for R-410A systems more than it does for R-22 units. Utilizing water for evaporative cooling only when the dry bulb temperature rises over 32.2ºC is one way to conserve water, as opposed to utilizing it throughout the cooling season. To optimize the annual operating cost savings and minimize water use, it may be advantageous for R-22 to utilize water only when dry bulb temperatures surpass 32.2ºC. It is important to note, nevertheless, that utilizing R-410A results in far larger annual and peak energy reductions than using R-22. Additionally, if the equipment is used at all dry bulb temperatures rather than just when the dry bulb surpasses 32.2ºC, R-410A can save even more energy [15].

### 3.3. Modelling of direct evaporative cooler

The transformation of sensible heat into latent heat is the basic idea behind direct evaporative cooling. The ambient air wet-bulb temperature is represented by the lowest temperature that can be reached. The unsaturated air cools through the process of heat and mass transfer.

The following definition applies to the total differential heat flow:

$$\delta Q = dA[h_c(T_s - T_a) + \rho_w h_{LVS} h_m (W_s - W_a)]. \quad (1)$$

Assuming that the vapour and air are ideal gases, the following can be determined using the mixture's specific enthalpy, which is the total of the individual enthalpies:

$$\delta Q = \frac{h_c dA}{c_{pu}}\left[(h_s - h_a) + \frac{(W_s - W_a)}{R_{Le}}(h_{LVS} - R_{Le} h_{VS})\right]. \quad (2)$$

If the magnitude of $R_{Le}$= 1, then, the second term in Eq. (12) can be ignored:

$$\delta Q = \frac{h_c dA}{c_{pu}}(h_s - h_a). \quad (3)$$

It can be written as

$$\delta Q_s = h_c dA(T_s - T_a). \quad (4)$$

The following relation is used to determine the effectiveness of direct evaporative cooling [18]:

$$\varepsilon = \frac{T_1 - T_2}{T_1 - T_s}. \quad (7)$$

Accordingly,

$$\varepsilon = 1 - \exp\left(-\frac{h_c A}{\dot{m}_a c_{pu}}\right). \quad (8)$$

The following relationship determined the coefficient of convection heat transfer across an evaporative medium of cellulose as reported by Dowdy and Karabash [19]:

$$\mathrm{Nu} = 0.10\left(\frac{l_e}{l}\right)^{0.12} \mathrm{Re}^{0.8}\mathrm{Pr}^{0.33}, \quad (9)$$

where $l_e$ is defined as

$$l_e = \frac{\vartheta}{A}. \quad (10)$$

### 3.4. System description

The study was conducted in Karbala, Iraq, located at a latitude of 32º and longitude of 44º. The maximum temperature in this city during the summer is 49.5ºC, according to data from the Iraqi Meteorological Organization [1]. That was on August 12, 2022, and the relative humidity at that temperature was 12%. Thus, this day is selected in the current work starting from 8 a.m. to 5 p.m.

The hot outside air passes through the cooling pad unit, to which water is pumped from the top. The hot outside air is evaporatively cooled, and then the air enters the condensing unit and the refrigerant entering into the condensing unit is cooled, as shown in Fig. 1.

## 4. Result and discussion

The air temperature as it exits the cooling pad unit and enters the condensing coil ($T_{cond}$) was calculated at different times of the day (from eight in the morning until five in the evening). Figure 2 shows the change in dry bulb outdoor air temperature, relative humidity and temperature of the air exit from the cooling pad unit at different periods of the daytimes.

The temperature of the air leaving the cooling pad unit ($T_{cond}$) increases with time and then decreases with increasing temperature and decreasing humidity. This helps the split air-conditioning unit perform well during peak hours, as increases COP and decreases electrical energy consumption. It is interested to mention that the average temperature of the air leaving the cooling pad unit in the extreme summer of the Karbala city is less than 32.2ºC at which the standard COP is 2.96. Therefore, COP of the split air-conditioning unit that uses evaporative cooling is always higher than the standard COP in the city of Karbala.

It can be concluded that the use of evaporative cooling in the split air condition unit is considered a very good solution to confront high temperatures, increase electrical energy consumption, and obtain COP higher than the standard at all times of summer.

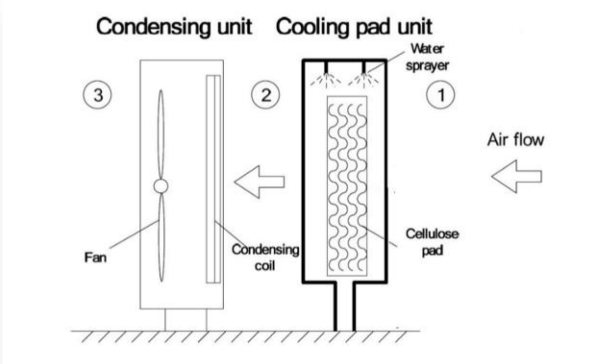


Fig. 1. A schematic illustration of the evaporative cooling system.

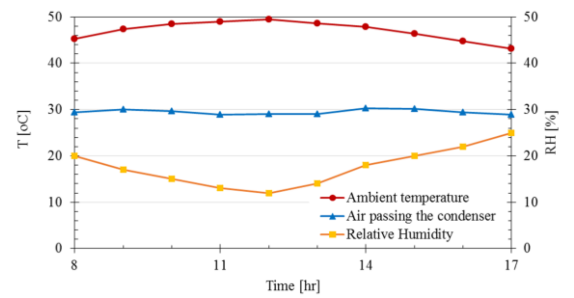


Fig. 2. Change of outside air temperature, relative humidity, and temperature of air passing the condenser ($T_{cond}$) with time.

The psychometric chart's process lines for the condenser's outdoor air temperature were constructed using the relative humidity and dry bulb. The enthalpy change through the evaporative-cooled condenser (referred to as DEC) and conventional condenser (referred to as CV) is shown in Fig. 3. Process line 1 to 2 demonstrates how the sensible heat transferred from the refrigerant raised the air temperature through the traditional condenser while maintaining a steady humidity ratio. The refrigerant phase change was the initial cause of the heat released into the air from the condenser. But in the case of the evaporative cooled condenser, latent heat transfer from the evaporation of water passing through the wetted medium caused the air temperature to drop from $T_1$ to $T_3$, and the humidity ratio to rise from

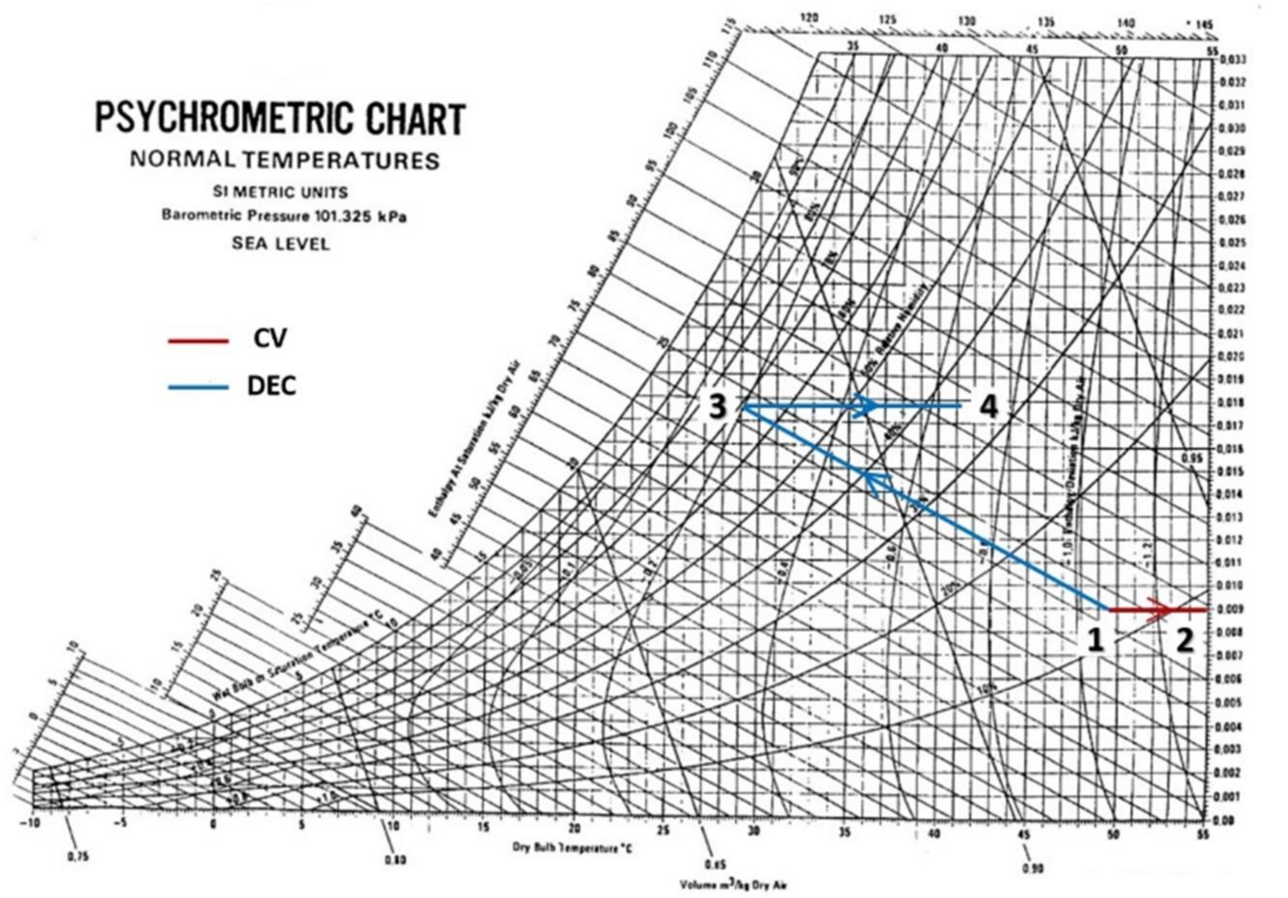


Fig. 3. Psychometric chart of the condenser air.

$W_1$ to $W_3$. This process is represented by line 1–3 in Fig. 3, known as an adiabatic process or a constant enthalpy line. The process line 3–4 illustrates the temperature of the air passing across the condenser which increases by the sensible heat transfer obtained from the heat rejected by the refrigerant inside the condenser. The chart shown in Fig. 3 indicates that the evaporative cooled condenser has a process line of 1–3–4, whereas the traditional condenser has a process line of 1–2. The wetted cooling pad surface drew heat from the surrounding air during the process of evaporative cooling, which led to sensible heat loss from the air and consequent latent heat uptake by the water.

## 5. Conclusions

Using an air-cooled condenser in hot climates, especially in the middle of summer when temperatures are more than 50ºC, leads to a rise in the pressure and temperature of the refrigerant gas coming out of the compressor, which in turn increases the electrical energy consumption and decreases the coefficient of performance, and may end up causing the compressor to stop working ultimately.

Using an evaporative cooling condenser to be integrated with a split air condition unit leads to the following conclusions:

- The use of evaporative cooling in a split air conditioner enhances performance, making it an effective method for reducing energy consumption and maintaining high values of coefficient of performance through the summer. The performance enhancement is achieved by lowering the condensing temperature.
- Considering the extremely hot summer in the Karbala city, the air temperature leaving the cooling pad unit reaches below 32.2ºC. As a result, the typical COP of 2.96 is exceeded.
- The required amount of the evaporative condenser's airflow rate is lower than that for air-cooled condensers.
- By using the same condenser evaporative pre-cooling, the R-410A system receives a greater reduction in the relative power compared to the R-22 system. Consequently, it can be suggested that the R-410A system is highly exposed to increasing external temperature.
- The current findings show the potential of reducing the required chemical treatment and water pumping for water-cooled condensers.

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