Energy Saving In A Split-Type Air Onditioner With Evaporative Cooling Systems

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Abstract

The reduction in the power consumption is very important especially in areas with high temperatures such as Iraq, where the power consumption by the air conditioner is very high. The conventional split-type air conditioner widely used in small and medium size buildings, e.g. residences, offices, and schools. In this work the evaporative cooling unit is designed at the department of Mechanical Engineering of the College of Engineering University of Basrah.. The evaporative cooling unit is connected in front of the condenser to decrease the inlet temperature of the condenser. In addition, their performances depend on the heat transfer between condenser and the ambient airflow. The reduction in the inlet air temperature to the condenser of the air conditioning that leads to reduce the power consumption and enhancement of the coefficient of performance for the refrigeration cycle. The experimental results show: the average power saving is 23%.

Keywords: Power saving; Coefficient of performance (COP); the ambient temperature.

الخلاصة:

الانخفاض في استهلاك الطاقة جدا مهم وخاصة في المناطق ذات درجات الحرارة العالية مثل العراق، حيث يكون استهلاك الطاقة من قبل أجهزة تكييف الهواء جدا مرتفع. جهاز التكيف يستخدم على نطاق واسع في المباني الصغيرة والمتوسطة الحجم، على سبيل المثال : المساكن و المكاتب والمدارس. في هذا البحث تم تصميم وحدة تبريد تبخيري في قسم الهندسة الميكانيكية في كلية الهندسة جامعة البصرة. حيث تم ربط وحدة التبريد التبخيري امام المكثف في جهاز التبريد وذلك لتقليل درجة حرارة الهواء الداخل الى المكثف. وبالإضافة إلى ذلك، معامل الاداء يعتمد على انتقال الحرارة بين المكثف و درجة حرارة الهواء المحيط ، حيث ان انخفاض درجة حرارة الهواء الداخل إلى المكثف يؤدي إلى تقليل استهلاك الطاقة وتحسين معامل الأداء لدورة التبريد الانضغاطية. وتظهر النتائج العملية: معدل توفير الطاقة هو ٢٣٪.

1- Introduction

Heating, Ventilation and Air Conditioning (HVAC) systems, which play an important part in ensuring occupant comfort, are among the largest power consumers in buildings. Performance enhancements to traditional Heating, Ventilation and Air Conditioning (HVAC) systems therefore offer an exciting opportunity for significant reductions in the power consumption. A closer look at worldwide energy consumption by Heating, Ventilation and Air Conditioning (HVAC) systems shows noticeable values such as: In the United States (USA), (HVAC) equipment constitute over 50% of the building energy consumption [1]. In China, the building power consumption has been increasing about 10% a year for the past 20 years and has comprised about 20.7% of the total national power usage by the year 2004 [2]. In Hong Kong air conditioning and refrigeration systems accounted for 33% in 2006 [3]. More than 70% of the building power consumption is to support cooling systems in Middle East [4]. It was found that world power consumption was increased by 58% between 2001 and 2005 [5]. In order to increase the coefficient of performance of air conditioner in this situation, one of the best solutions is decreasing the condenser temperature. Reducing the condenser temperature reduces the pressure ratio across the compressor which results power consumption reduction. To reduce the condenser temperature, one of the easiest ways is the application of the direct evaporative cooling unit in front of the condenser to cool down the air temperature before it passes over the condenser. Using the evaporative cooling unit in front of the air condenser can be considered as power efficient, environment friendly and cost-effective method to improve the coefficient of performance of air conditioners. Since huge numbers of air conditioners are used in the residential sector, therefore, any considerable enhancement in the coefficient of performance of the cycle will have huge effect on the energy consumption of the whole network [6]. In 2011, Yu and Chan, [7] investigated how to decrease the dry bulb temperature of ambient air via mist pre-cooling to improve the coefficient of performance (COP) and decreasing the power consumption of an air-cooled chiller system. The mist pre-cooling method is used in a hotel in Hong Kong to enhance the energy consumption. Their results estimated that around 18% decrease in the power consumption could be achieved with using mist precooling of air entering. Wang, et al, (2014) [8] presented an experimental investigation of the Coefficient of Performance (COP)'s augmentation of an air conditioning system utilizing an evaporative cooling condenser. The experimental facility consisted of four major components, which are, the compressor, the evaporator, the thermostatic expansion valve, and the condenser. An evaporative cooling unit was located upstream from the condenser. By using the evaporative cooling unit to pre-cool the air that lead to reduce the power consumption and enhancement of COP.

2- Theoretical analysis:

Theoretical Analysis for the evaporative cooling unit and the condenser of the air conditioner. To simplify the heat and mass transfer analysis, the following assumptions are used: 1-The cellulose pad is wetted uniformly and fully. 2- The thermal properties of air and water are constant. 3- Adiabatic compression process.

2.1 Theoretical analysis of the evaporative cooling unit:

Can find the temperature after the cellulose pad as following below.

The sensible heat removed from the air stream through the cellulose pad shown in fig.1 in air flow direction can be written as:

$$dQ_{sen} = h_e \,.(T_a - T_w).dA \qquad (1)$$

where,

$$dA = F\,.B.H.dx \qquad (2)$$

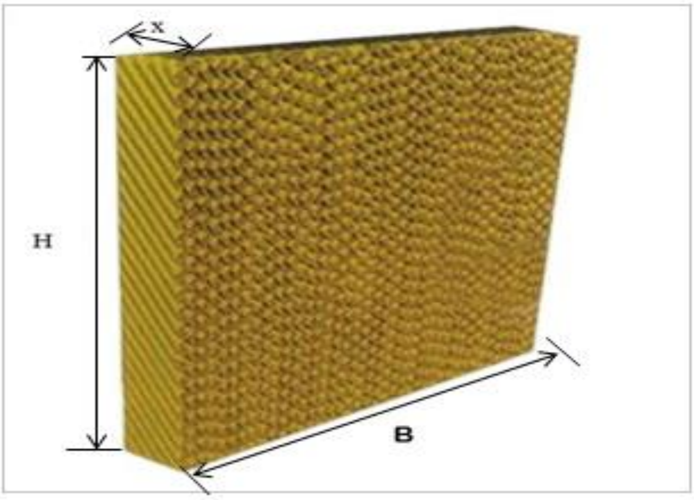


Fig.1 the cellulose pad

Thus, Eq. (1) may be written as:

$$dQ_{sen} = h_e \,.(T_a - T_w).F\,.B.H.dx \qquad (3)$$

and,

$$dQ_{sen} = -\dot{m}_a \,.cp_a.dT \qquad (4)$$

Similarly the equations (3) and (4)

$$-\dot{m}_a \,.\, cp_a . dT = h_e \,.\, (T_a - T_w). F \,.\, B. H. dx \qquad (5)$$

The inlet boundary conditions for Eq. (3) are:

$T_a = T_{a1}$, at $x=0$ (6)

By solving Eqs. (5)–(6), the changes of temperature along with x are obtained :

$$T_a = T_s + (T_{a1} - T_w). \exp\left(-\frac{h_e.F.B.H.x}{\dot{m}_a.cp_a}\right) \qquad (7)$$

2.2 Theoretical analysis of the air conditioning condenser:

The condenser is a heat exchanger that rejects heat from the refrigerant to the outside air. Refrigerant flows through the tubes and a fan forces air between the fins and over the tubes. When the refrigerant leaves the compressor, it enters the condenser as a superheated vapor and leaves as a sub-cooled liquid. The condenser can be divided into three sections: superheated steam section, two phase flow section, and sub-cooled liquid section.

2.2.1 Refrigerant Side Heat Transfer

The heat transfer coefficient for the two phase flow region is calculated from the Dittus-Boelter correlation as follows [9]:

$$h_{tp} = h_l \left[(1-x)^{0.8} + \frac{3.8\, x^{0.76}(1-x)^{0.04}}{p_{re}^{0.38}}\right] \qquad (8)$$

and;

$$h_l = \frac{K_{Lq}}{d}\left(0.023\left(\frac{Re_{lq}}{1-x}\right)^{0.8} Pr_{liq}{}^{0.4}\right) \qquad (9)$$

Where,

$$Re_l = \frac{g.d.(1-x)}{\mu_l} \qquad (10)$$

$$Pr_{liq} = \frac{cp_l.\mu_l}{k_l} \qquad (11)$$

2.3 Estimation of the power saving:

The power saving is the ratio of the difference between the power consumption without and with evaporative cooling unit to the power consumption without evaporative cooling unit.

The experimental results of the power saving of the compressor can be calculated as follows:

$$\text{Power saving} = \frac{p_{woe} - p_{we}}{p_{woe}} * 100\% \qquad (12)$$

2.4 The Coefficient of Performance (COP):

The Coefficient of Performance (COP) can clarify the air conditioner Performance, which is given by: (see fig.2)

$$COP = \frac{Q}{W} \tag{13}$$

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \tag{14}$$

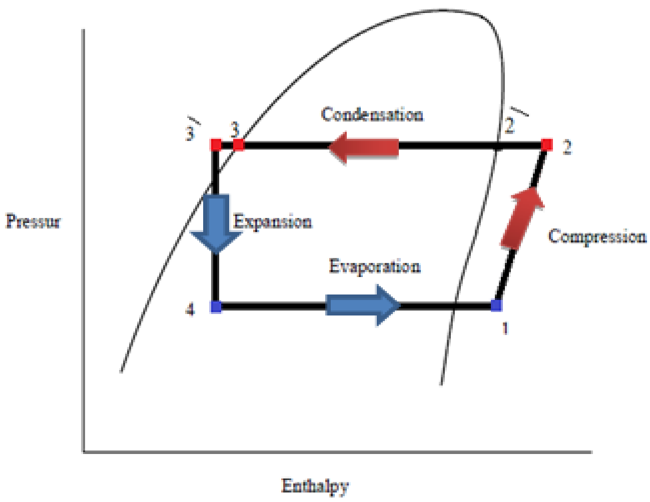


Fig.2 Typical vapor compression refrigeration cycle. [10]

3. Experimental work:

The power saving is performed by using evaporative cooling unit with condensing unit in a laboratory split-type air conditioner. The evaporative cooling unit used to enhance the condenser performance of split-type air conditioner. In this study designed and manufactured evaporative cooling unit that is retrofitted to the condenser of split unit type air conditioner as shown figure (3). The evaporative cooling unit is simple and cheapest way for cooling ambient temperature as shown figure (4). The device split-type air conditioner can be shown in figure (5). The evaporative cooling unit is manufactured from Aluminum plate and covered by the isolator glass wool as shown figure (6). It is very important to decrease the power consumption of split unit in very high ambient temperature and to do this, it is required to decrease the inlet air temperature of the condenser (see fig.7).

The cellulose pad put in the face of the evaporative cooling unit, it has made from small pieces of wood. It can be used to cool and humidified the air because it is wetted by the water which pump by the water pump and collected in water sump. The dimension of the evaporative cooling unit is (55cm×30cm×20cm).

The evaporative cooling unit, which consist of the following parts (see fig.8):

1-Water pumping pipe. 2- Water pump. 3- Water sump. 4- Air duct. 5-Cellulose Pad.

6- Isolator. 7- Base.

1.Water pumping pipe:

This system is made using a plastic pipe to distribute water on top of the cellulose Pad. The diameter of water pumping pipe is 1 cm.

2. Water pump:

It is used to pump water from the basin to the top of the cellulose Pad. Specification of water pump, 220-volts, 50 Hz, 20 watt, max head 2 m and max flow rate 20 l/min.

3. Water sump:

Water sump has made from galvanized iron. It uses to collect the falling water from the wetted pad. The dimension of the water sump is 60 cm×30 cm×15 cm.

4. Air duct:

Air duct is a stream of the inlet air to the condenser. It has made from Aluminum material and covered by two layers of isolator. The dimensions of air duct are 20 cm×50 cm ×55 cm.

5. Cellulose Pad:

The cellulose pad has made from small pieces of wood. It can be used to cool and humidified the air. It put in front of the air duct. The dimensions of the cellulose pad are 4 cm thickness, 50 cm height, 55 cm width.

6. Isolator:

Isolator covered the air duct by two layers, it use to prevent the heat transfer to inside the air duct. It has made from glass wool. Thickness of isolator is 2 cm.

7. Base:

Base used to evaluate up the water sump and air duct. It has made from cast iron.

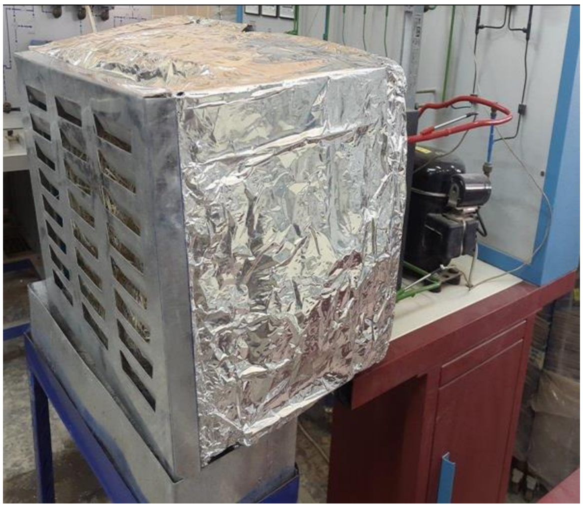
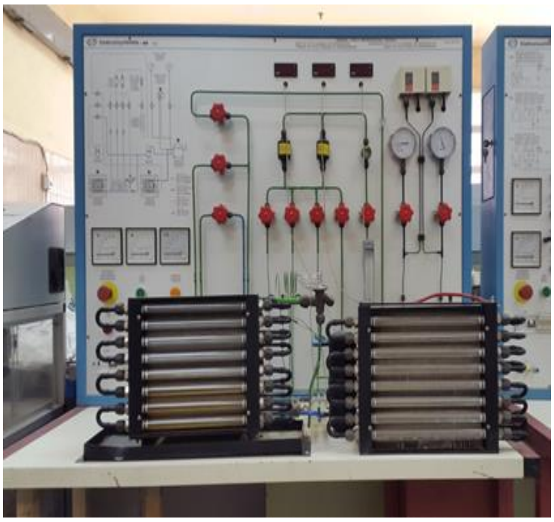


Fig.3: apparatus with evaporative cooling unit

Fig.4: face of the evaporative cooling unit



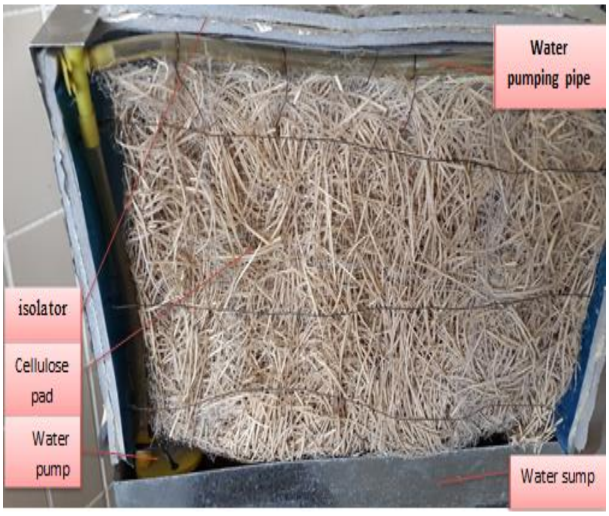


Fig.5: Components of the experimental apparatus Fig.6: apparatus with the evaporative cooling

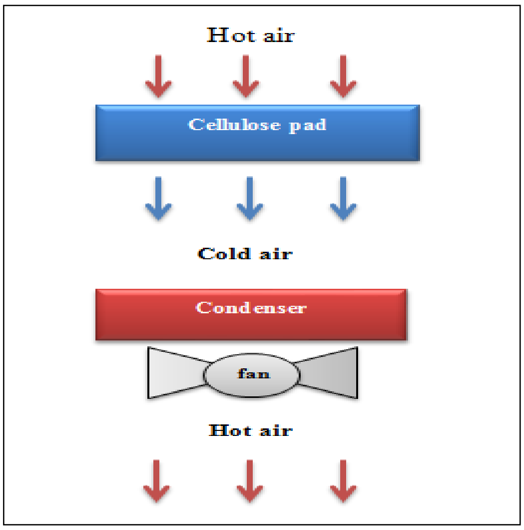


Fig.7 Schematic diagram of air circulation

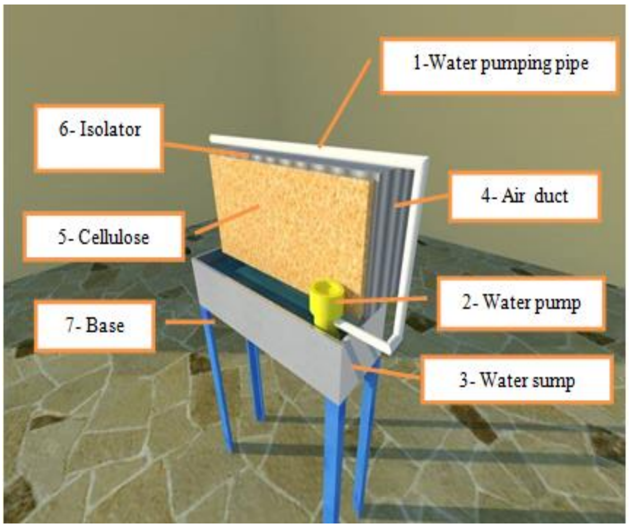


Fig.8 the evaporative cooling unit

4. Results and discussion:

The experimental data are recorded for five months (April, May, June, July and August). The results consist of two statements :-

state1: Air Condition (A.C) without using the evaporative cooling unit.

state2: Air Condition (A.C) with using the evaporative cooling unit.

Refrigerant fluid is R143a .

Fig.9 shows the variation of the outlet air temperature for the condenser between state1 and state2 for the same inlet air temperature. Its noted when the ambient temperature is 45 $°C$, the outlet temperature of the condenser at state1 is 50.5 $°C$ and for state2 is 41 $°C$.

Fig.10 shows the experimental power consumption vs. the inlet air temperature. This figure explains the effect of the evaporative cooling unit on the power consumption of the compressor. Its noted that the energy consumption decrease in state2 because decreased in the inlet temperature. The maximum power consumption for state1 is 520W while the maximum power consumption state 2 is 410W, when the ambient temperature is 45 $°C$.

Fig.11 explains the experimental results of the condenser pressure vs. the inlet air temperature for state1 and state2. At state2, the inlet air temperature decreased that lead to decrease the condenser pressure. The maximum of the condenser pressure for state1 is 15.5 bar and the maximum of the condenser pressure for state2 is 12.2 bar.

Fig.12 explains the behavior of the heat transfer coefficient along the two phase flow region of the condenser. The heat transfer coefficient at the first of the two phase flow region is high and then gradually decreases along the two phase region because the increased thermal resistance due to the increased in the thickness of the liquid condensate.

Fig.13 illustrates the experimental results of the power saving vs. the ambient temperature. Its noted that the power saving decreased with increasing the ambient temperature. The average power saving is 23% for the experimental results.

Fig.14 illustrated of the coefficient of performance (COP) at different the inlet air temperature. The results explained that the coefficient of performance (COP) decreases with increasing the inlet air temperature. Its noted when the inlet air temperature is 45 $°C$, the coefficient of performance (COP) with using the evaporative unit (state2) is 5.53 and without using the evaporative unit (state1) is 4.52.

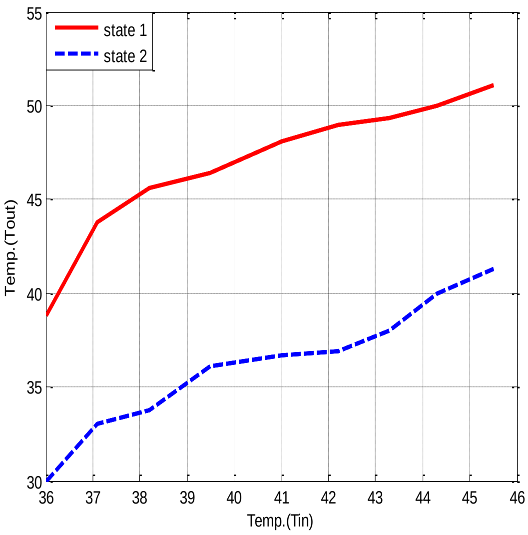


Fig.9: outlet and inlet temperature from condenser

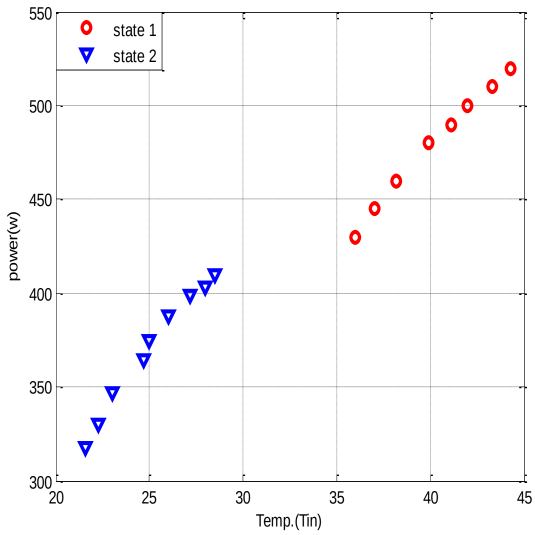


Fig.10: power vs. the inlet temperature.

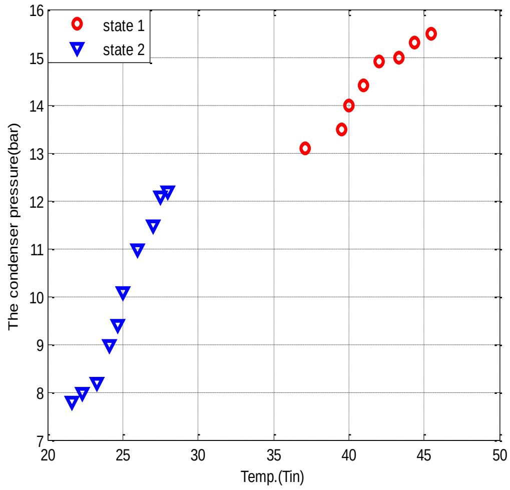


Fig.11: condenser pressure vs. the inlet temperature

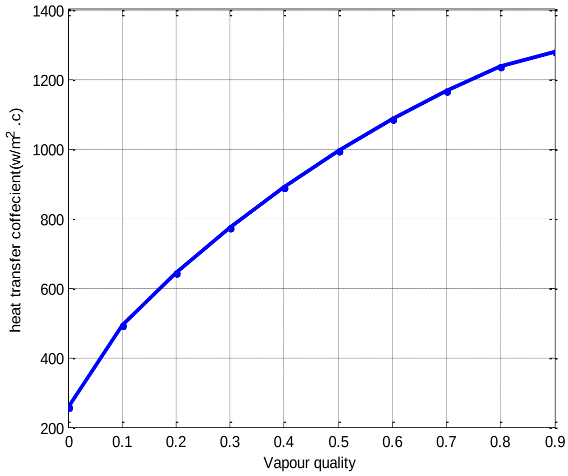


Fig.12: Vapor quality vs. heat transfer Coefficient

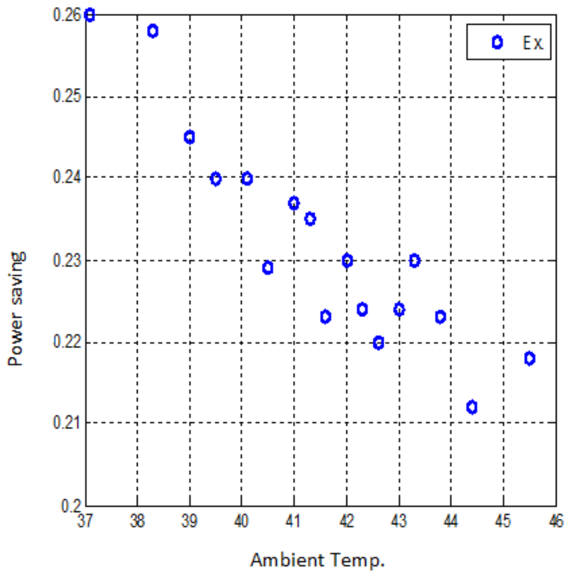


Fig.13: power saving vs. the ambient temperature

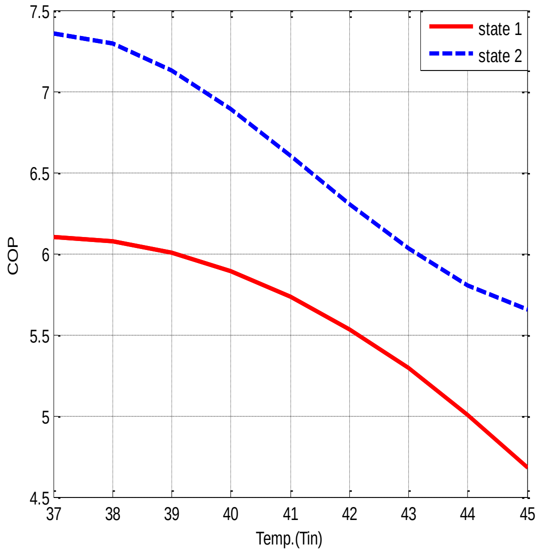


Fig.14: COP profile vs. the inlet air temperature

5.Conclusions:

The reduction in the power consumption is very important in many countries especially in areas with high temperatures such as Iraq, where the power consumption by the air conditioner is very high. Experimental results showed:

1- The power consumption decrease with decreasing the ambient temperature.
2- The average power saving is 23% for the experimental results.
3- The coefficient of performance increase with decreasing the ambient temperature. COP is 5.53 when using evaporating cooling unit.

4- The proposed system has better performance and also the cost of installing the system is very low, therefore, its application in hot weather condition is highly recommended.

5- The potential of commercialization of the proposed system is very high since it can be easily coupled to the existing system with low cost.

6- Application the evaporative cooling unit of the air conditioning will reduce the peak load of the power network in hot weather area because the vapor compression air conditioners are usually responsible for the peak load.

Nomenclature

Symbols	Definition	Unit
B	Width of the cellulose pad	m
cp_a	Specific heat of air	J.$kg^{-1}c^{-1}$
d	Diameter of the condenser tube	m
F	Pore surface coefficient per unit padding Volume	m^2/m^3
g	Refrigerant Mass Flux	Kg.$m^{-2}.s^{-1}$
h_e	Convective heat transfer coefficient	$W.m^{-2}.c^{-1}$
h_{tp}	Heat transfer coefficient the two phase flow region	W.$m^{-2}.c^{-1}$
h_l	Heat transfer coefficient of the liquid region	W.$m^{-2}.c^{-1}$
H	height of the cellulose pad	m
$\dot{m}_a$	Mass flow rate of air	kg.s^{-1}
Pr_{liq}	Prandtl number for the liquid region	--
p_{re}	Reduce pressure	--
Q_{sen}	Sensible heat transfer rate	W
Q	Refrigerating effect	KJ/kg
Re_l	Reynolds number for the liquid region	--
T_a	Air dry-bulb temperature	^oC
T_w	Water film temperature	^oC
T_s	Air wet-bulb temperature	^oC
W	Work done	KJ/Kg
x	Vapor quality	--

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