Enhancement the Performance of Condenser of Split Type Air Conditioning System by Using Evaporative Cooling

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Abstract:

The reduction of energy demand is a major concern in areas with very hot weather conditions about 50C^{o}. This can be achieved by using more energy efficient equipment. Evaporative cooling provides a low cost, energy efficient and environmental friendly alternative to traditional Air Conditioning. In this study, a simple design of applying indirect evaporative cooling which investigated experimentally to improve the coefficient of performance of split unit and power consumption. This model consists of a cooling pad behind condenser and injected water on it to reduce air temperature before it passes over the condenser. The experimental results show that the coefficient of performance increases by about 73% and the power consumption decreases by about 18%.

Key words: Evaporative cooling, air conditioning system, Energy reduction, Coefficient of performance.

تحسين أداء مكثف منظومة تبريد نوع سبلت باستخدام تبريد تبخيري

م.م لينا إسماعيل جاسم
قسم الميكانيك/كلية الهندسة /الجامعة المستنصرية

المستخلص:

يتضمن هذا البحث، تصميم نموذج عملي لتحسين اداء منظومة التبريد، والتقليل من استهلاك الطاقة الكهربائية خاصة في المناطق ذات الدرجة الحرارية العالية، والتي تصل إلى حوالي ٥٠ درجة مئوية وذلك باستخدام التبريد التبخيري. ان النموذج المستخدم يتضمن وسيط تبريد تبخيري، وهو مادة الحلفة بشكل يشبه تصميم المكثف الخاص بالسبلت، موضوعة خلف المكثف لتبريد الهواء قبل مروره على ملف المكثف، وحوض ماء ومضخة صغيرة وانابيب توصيل الماء. علما ان النتائج العملية تشير الى زيادة في معامل اداء المنظومة بنسبة ٧٣% وانخفاض باستهلاك الطاقة الكهربائية بنسبة ١٨%.

1. Introduction

Air conditioning is commonly used in a wide range for residence, building, offices and hotels. Most air conditioner types for this purpose are called "split type" that is divided into two parts are fan coil unit and condensing unit where the fan coil unit is located inside the room and another one is located outside the room. In air conditioning system, there are three kinds of condensers using: air-cooled, evaporative-cooled, and water-cooled. Condensers used in conventional small tonnage residential split air conditioners are mostly air cooled.

The performance of split air conditioner depends on heat transfer between the coils and the airflow. In this regard, air-cooled condensers need a high airflow rate for improved performance, and thus sometimes results in noise problem. So in general, the coefficient of performance can be improved by lowering the compressor power consumption, increasing the cooling and heat rejection capacity, decreasing the refrigerant pressure loss, or reducing the pressure difference between the condenser and evaporator. Reducing the pressure difference between the condenser and evaporator is the fruitful one in comparison with those mentioned above. While the evaporating temperature is kept constant, lowering the condensing temperature results in the reduction of pressure difference. Typically air-cooled condensers are of the round tube and fin type. To improve the performance of air-cooled condensers, multiple techniques can be achieved such as enhancements on inner pipe surface, changing the tube geometry from a round to flat shape and external fins. [1].

Chow et al, [2], reported that if the on-coil temperature of a condensing unit were raised by 1 ^{o}C, the coefficient of performance (COP) of the air conditioner would drop by around 3%. In addition, if this temperature remained above 45 ^{o}C for an extended period, the air conditioner would trip because of the excessive condenser working pressure.

Hwang [3] carried out a 7.4 kW residential split heat pump system utilizing an innovative design of evaporative-cooled condenser. The condenser was 1 m wide, 0.66 m long and 0.66 m high. The heat to be removed from condenser was placed in a cooling water tank where the condenser tubes were immersed. The heated water in the tank was lifted by the rotating disks which partly immersed in the water

and then cooled by the cooling air flow. The test results showed that COP was increased by 11.1–21.6% as compared to the air-cooled condenser. However, the size of Hwangs system was too large, heavy and complicated for residential application. A simple prototype of water-cooled air conditioner of split type developed by Huang and et al. [4] by using cellulose pad as the filling material of the cooling tower. The experimental results showed the coefficient of performance COP reaches 3.45 at wet bulb temperature 27 ^{o}C, dry bulb temperature is 35 ^{o}C and that is higher than the standard value 2.96 of those conventional residential air conditioners. Chainarong C. and P. Doungsong [5] proposed an experimental study to evaluate the energy saving in a split type air conditioner, which used various types of evaporative cooling system. The results showed that electrical consumption and coefficient of performance significantly depend on the ambient temperature rises. Goswami et.al.[6] employed an evaporative cooling on existing 2.5 ton air conditioning system by using media pad. They put four media pad around the condenser and inject water from top by a small water pump. They reported the electric energy saving of 20% for the retrofitted system when ambient air temperature was 34C^{0}.

We used the evaporative cooling to enhance condenser performance of split air conditioner due to its characteristics of zero pollution, energy efficiency, simplicity and good indoor air quality. This study deals with designing and manufacturing a model of using evaporative cooling with a condenser of split unit type of air conditionining. This idea seems reasonable as far as the air temperature in summer is moderate and dose not reach 40C^{o}, but when the air temperature increases and approaches 50C^{o} or higher, as it happens in many Middle East countries, the performance of the air condenser drops down and the air conditioner or split unit works improperly since the temperature and the pressure of the condenser increases and the compressor is forced to work under the greater pressure ratio. This results in more power consumption. Therefore, it is very important to decrease the power consumption of split unit in very hot ambient temperature. To do this, it is required to decrease the temperature of the ambient air before it passes over the condenser coil, in order to decrease temperature and pressure of the condenser. The simple and cheapest way for cooling ambient air temperature is employing the evaporative cooling system. This could

result in significant energy and demand saving overall since there are millions of split units in the residential sector and any small reduction in power consumption of split unit could save huge amount of megawatt in the network.

2. Description of Experimental Set Up.

The experimental set-up studied here mainly consists of the application of evaporative cooling in an existing residential air conditioner or split unit type of air conditioning system. This study applied on split type of two tons in the laboratory of Mechanical Department, in Engineering College, Al-Mustansiriyah University (see Fig.1) which refers to evaporative cooling process. There are two methods of evaporation; first direct and the indirect method. In the direct method, water is directly injected on the condenser and provides a cooling effect. This method has many side effects including mineral deposits and corrosion of the condenser coils. Therefore, this method has rarely been used in residential split type air conditioning system. In the indirect method, water is injected on the evaporative media pad which is located in a way to cover the air around the condenser and provides a cooling effect by water evaporation. The place of media pad should be installed in a way to give a good cooling effect and also takes minimum space from outside partition of our equipment. The limitation of space is very important in our design consideration. In this work, one evaporative media pad, media pad is cellulose bound structures with height 54cm, width of media pad in curve shape with angle 90^0 so the length of long side is 74cm and short side 26cm and 5cm thickness, this pad is installed behind the condenser and the distance between them is 2.5cm to give the largest area available for cooling without increasing the total volume of outside partition of our device. For air circulation, hot ambient air passes over the evaporative media pad and after cooling down passes over the condenser and finally exits by fan which is located in front of the condenser as is shown in figure 2., in this figure the ambient conditions are found in Table 3. The conditions of hot air in Run B is D.B.T= $40C^0$, W.B.T= $22.5C^0$, and R.H= 21%, the conditions after media pad is D.B.T=$36.5C^0$, W.B.T=$24.5C^0$, and R.H=37%, and after condenser fans is D.B.T=$45C^0$, W.B.T=$24.5C^0$, and R.H=19%. While the ambient conditions of Run B can be found in Table 4. This is

because the water circulation system was built to spray water on the top of the media pad in the way shown in figure1. It includes a small pump, simple tank with dimensions are (92cm, 91cm, 10cm) and pipes as are shown in figure 3. Individual power meter was used to measure the electrical current consumption of the compressor. Temperature of the refrigerant and circulation air at different points were recorded by thermocouple instrument and pressure gages. The water consumption rate due to evaporation process was measured by measuring water level decrease in the tank during the test period.

Fig.1. Picture of experimental apparatus with condenser and evaporator devices.

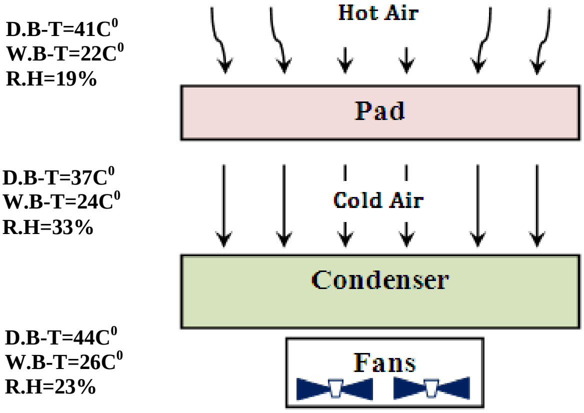


Fig.2. Schematic diagram of air circulation of Run A.

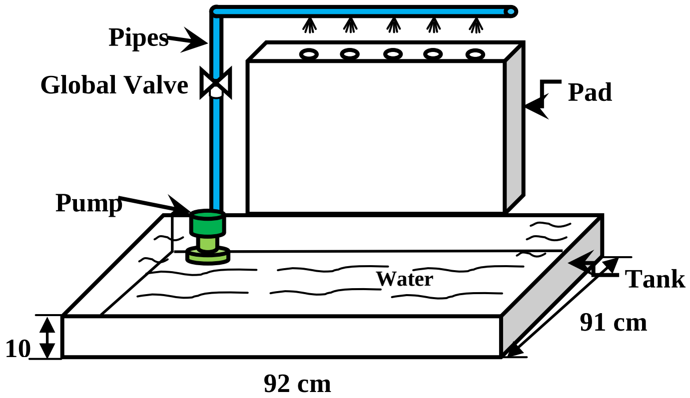
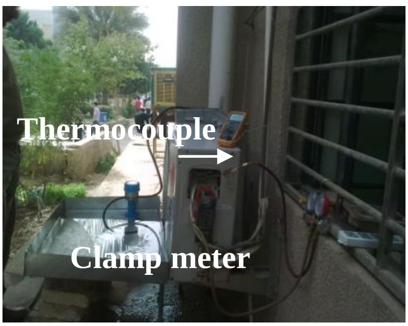


Fig.3. Schematic diagram of water circulation in evaporative unit.



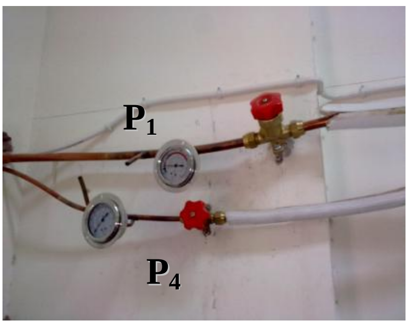


Figure 4. Picture of the pressures meters, thermocouple instrument, and power meter.

3. Experimental Data and Calculations

An experimental laboratory study has been on a split unit air conditioner with a 2 TR nominal capacity, tables 3 and 4 explain the outside and inside laboratory air conditions, taking into consideration the effect of outdoor ambient temperature and by using the simplest possibilities and minimum costs. A split unit of 2 TR was installed in Air Conditioning Laboratory of engineering College of Al- Mustansiriyah University. The room temperature was fixed by fixing the cooling load refrigerant inside laboratory, when the weather conditions are constant at the time of testing. Many tests were performed of reading but we write down two sets of this study for each ambient outdoor temperature without any modification. The two sets of readings were taken with evaporative cooling. The time difference between two states was small (about 15 min) after steady state. So the weather condition was the same. In all experiments, the data recorded after steady state conditions. Many experiments were performed to determine the effect of evaporative cooling on the performance of an air conditioning system of split type. The data of an experimental run A are shown in Fig 5.and Table 1[all data in Tables 1&2 are read by instruments as is shown in Fig.4]. Fig.5 shows the data on pressure enthalpy (P– h) diagram. So, when we apply evaporative cooling, pressure in the condenser is reduced from 2082 kPa to 1255.5 kPa, which shows a 39% reduction, but the pressure in the evaporator is reduced from 517 kPa to 427 kPa which shows 17% reduction. Therefore, pressure ratio across the cycle reduces from 4 to 2.9 which have 26% reduction. This reduction is an indication of power reduction in the system. The coefficient of performance can be improved by lowering the compressor power consumption, increasing the cooling and heat rejection capacity, decreasing the refrigerant pressure loos, or reducing the pressure difference between the condenser and evaporator.. Table.1 shows the difference between temperatures in evaporator in two states are 5 °C and in condenser 27 °C, which indicates the reduction in pressure ratio of cycle. Referring to Table.1, we notice the consumption of electrical power reduces about 15% and reaches to 9.2 A from 10.9 A. If the power consumption of small pump is obtained by equation (1), therefore the actual power consumption of split unit system is equal the compressor power consumption and pump power consumption, when the electric current of pump is 0.3 A. The experimental data shows to

the degree of accuracy of measuring temperature and pressure data in the condenser, when it compared with thermodynamic tables. Referring to Table 1, the condenser temperature in state 1 is about 56 $^{\circ}$C and from thermodynamic tables it can be seen that the saturation pressure of R-22 in this temperature is 2.1753 MPa. On the other hand, the pressure reading in state 1 is (2082.2) kPa which has negligible defference with the saturation pressure of R22 in 56 $^{\circ}$C. The same accuracy in temperature and pressure readings also exits for data in the evaporator which indicates the reliability of experimental data. The experimental data for Run B are shown in Table 2. in this state despite the difficulty of measuring pressure in refrigeration cycle because the refrigerant tends to escape from the pressure gauge connections and fittings. But we decide to read them so see the pressure enthalpy (P- h) diagram in Fig 6. In Table 2 the condensing temperature is 54 $^{\circ}$C and it is reduced about 9° C while the evaporator temperature reduction is about 2 $^{\circ}$C which is an indication of reducing the pressure across the compressor. Exit air temperature from evaporator is 14 $^{\circ}$C while the exit air temperature is almost constant. Electric power reduction in this state is about, 16% water circulation rate is about 75 letter/hour (1/h) and evaporation rate is 7.5 letter /hour (l /h).

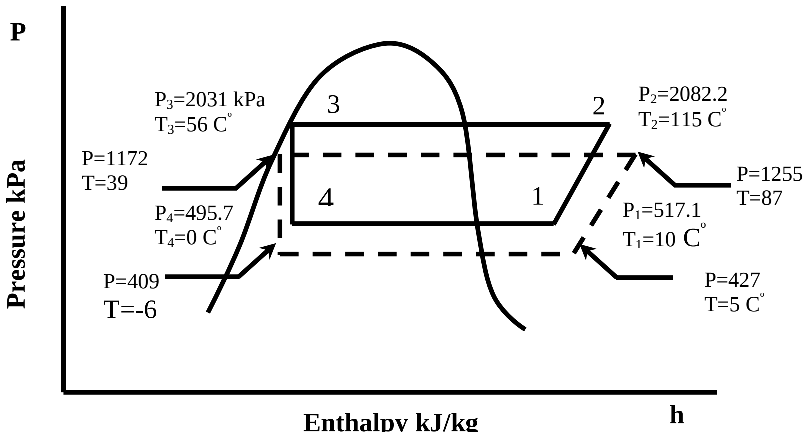
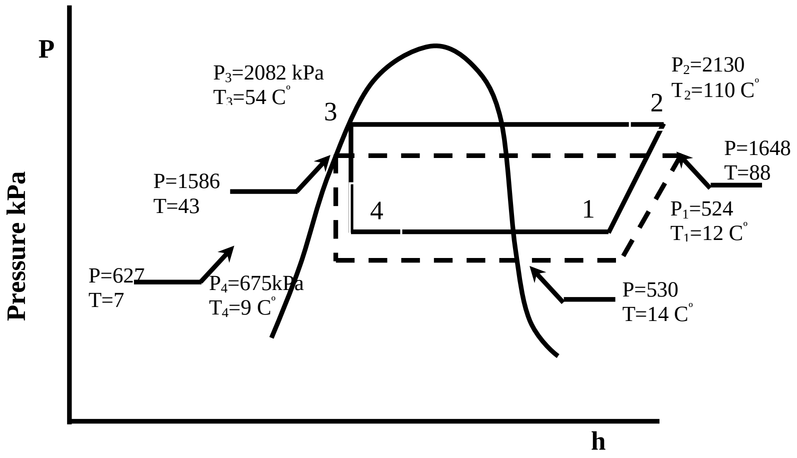


Figure. 5. P-h Diagram of with and without evaporative cooling of Run A.



Enthalpy kJ/kg

Figure.6. P-h Diagram of with and without evaporative cooling of Run B

Table 1
Experimental data of the test (Run A)

Parameter	*Unit*	*Without Evaporative*	*With Evaporative*
Ambient dry bulb temperature.	**°C**	**45**	**45**
Ambient wet bulb temperature.	**°C**	**24**	**24**
Condenser inlet temperature.	**°C**	**115**	**87**
Condenser exit temperature.	**°C**	**56**	**39**
Capillary tube exit temperature.	**°C**	**0.0**	**-6**
Evaporator exit temperature.	**°C**	**10**	**5**
Condenser air exit temperature.	**°C**	**57.0**	**39**
Evaporator inlet air temperature.	**°C**	**25**	**24**
Evaporator exit air temperature.	**°C**	**17**	**15.5**
Electric current	**A**	**10.9**	**9.2**
Compressor exit press.	**kPa**	**2082**	**1255.5**
Condenser exit press.	**kPa**	**2031**	**1172**
Capillary exit press.	**kPa**	**495**	**409**
Evaporator exit press.	**kPa**	**517**	**427**
Water evaporation rate 1/h.	**1/h**		**7.5**
Water circulation rate 1/h.	**1/h**		**75**

Table 2
Experimental data of the test (Run B)

Parameter	*Unit*	*Without Evaporative*	*With Evaporative*
Ambient dry bulb temperature.	**°C**	**46**	**46**
Ambient wet bulb temperature.	**°C**	**25.5**	**25.5**
Condenser inlet temperature.	**°C**	**110**	**88.8**
Condenser exit temperature.	**°C**	**54**	**43.6**
Capillary tube exit temperature.	**°C**	**9**	**7**
Evaporator exit temperature.	**°C**	**12.5**	**14**
Condenser air exit temperature.	**°C**	**59**	**45**
Evaporator inlet air temperature.	**°C**	**27**	**27**
Evaporator exit air temperature.	**°C**	**18**	**17**
Electric current.	**A**	**12.5**	**10.5**
Water evaporation rate.	**l/h**		**7.5**
Water circulation rate.	**l/h**		**75**

Table 3
Air conditions Outside and inside laboratory Run A.

Parameter	*Unit*	*Without Evaporative*	*With Evaporative*
Ambient dry bulb temperature.	°C	45	45
Ambient wet bulb temperature.	°C	24	24
Relative humidity.	-	18%	18%
Inside dry bulb temperature without AC.	°C	32	32
Inside wet bulb temperature without AC.	°C	26	26
Inside relative humidity	-	64%	64%
Inside dry bulb temperature Run A.	°C	25	25
Inside wet bulb temperature Run A.	°C	19	19
Relative humidity Run A.	-	57%	60%

Table 4
Air conditions outside and inside laboratory Run B.

Parameter	*Unit*	*Without Evaporative*	*With Evaporative*
Ambient dry bulb temperature.	°C	46	46
Ambient wet bulb temperature.	°C	25.5,	25.5
Relative humidity.	-	19%	19%
Inside dry bulb temperature without AC.	°C	32	32
Inside wet bulb temperature without AC.	°C	25	25
Inside relative humidity	-	60%	60%
Inside dry bulb temperature Run B.	°C	27	27
Inside wet bulb temperature Run B.	°C	22	21
Relative humidity Run B.	-	60%	59%

To calculate the cooling capacity Q_c, refrigerant effect q_c and the coefficient of performance Cop, it is required to specify thermodynamic properties of refrigerant at different sections of the cycle based on experimental results. Tables 5, 6, 7 and 8 show the

thermodynamic properties of refrigerant for Run A and Run B [with and without evaporative cooling] based on data from ASHRAE 1997 [7].

Actual power consumption of compressor can be obtained by using Eq.1 since the voltage, current and Cos φ are known, and the power consumption of small pump is obtained by the same equation, therefore the actual power consumption of split unit system equals the compressor power consumption and pump power consumption, if the electric current of pump is 0.3 A. Mass

Flow rate $\dot{m}$ can be obtained by Eq.2 Cooling capacity Q_c and COP can be obtained by using Eq.3 and Eq.4 respectively and the compressor work can be calculated by Eq.5. and the volumetric efficiency η_v of a refrigeration compressor is defined as: the ratio of actual volume of gas entering the compressor to the geometric displacement of the compressor [8]. So Eq. 6 expressed the volumetric efficiency.

$$P_{cons} = VI\ Cos\theta \qquad \text{......(1)}$$

$$\dot{m} = \frac{W_c}{h_2 - h_1} \qquad \text{......(2)}$$

$$Q_c = \dot{m}\left(h_1 - h_3\right) \qquad \text{......(3)}$$

$$COP = \frac{Q_c}{W_c} = \frac{h_1 - h_3}{h_2 - h_1} \qquad \text{......(4)}$$

$$W_c = \dot{m}\left(h_2 - h_1\right) \qquad \text{......(5)}$$

$$\eta_v = \frac{V_a}{V_{dis}} \qquad \text{......(6)}$$

η_v can be obtained from ASHRAE System and Equipment Handbook [9], by using Figure showed the relationship between η_v and the compression ratio $P_{dis}/P_{suc} = P_2/P_1$, we choose the correct figure depending on the compressor type , so the compressor used in this study is Rotary type.

Table 5
Thermodynamic properties of R-22 (in state 1) Run A .

Parameter/Unit	*Evaporator*	*Compressor*	*Condenser*	*Capillary*
Temperature °C	T_1=10	T_2=115	T_3=56	T_4=0
Pressure kPa	P_1= 517.1	P_2= 2082	P_3= 2031	P_4= 495.7
Enthalpy kJ/kg	h_1=410	h_2=473	h_3=278	h_4=278
Density kg/m^3	ρ_1=20	ρ_2=68	ρ_3=500	ρ_4=700
Entropy kJ/kg.k	S_1=1.77	S_2=1.86	S_3=1	S_4=0.9

Table 6
Thermodynamic properties of R-22 (in state 2) Run A with evaporative cooling.

Parameter/Unit	*Evaporator*	*Compressor*	*Condenser*	*Capillary*
Temperature ºC	T1=5	T2=87.6	T3=40	T4=-6
Pressure kPa	P1= 427	P2= 1255.5	P3= 1170	P4= 409.55
Enthalpy kJ/kg	H1=410	h2=462	h3=249	h4=249
Density kg/m3	ρ1=19	ρ2=45	ρ3=400	ρ4=700
Entropy kJ/kg.k	S1=1.77	S2=1.82	S3=1	S4=0.9

Table 7
Thermodynamic properties of refrigerant R-22 without evaporative cooling Run B .

Parameter/Unit	*Evaporator*	*Compressor*	*Condenser*	*Capillary*
Temperature °C	T_1=12	T_2=110	T_3=54	T_4=9
Pressure kPa	P_1= 524	P_2= 2130.5	P_3= 2082	P_4= 675.68
Density kg/m^3	ρ_1=20	ρ_2=72	ρ_3=1098	ρ_4=70
Entropy kJ/kg.k	S_1=1.77	S_2=1.82	S_3=1.22	S_4=1.25
Enthalpy kJ/kg	H_1=412	h_2=460	h_3=270	h_4=270

Table 8
Thermodynamic properties of refrigerant R-22 with evaporative cooling Run B.

Parameter/Unit	*Evaporator*	*Compressor*	*Condenser*	*Capillary*
Temperature °C	T_1=14	T_2=88	T_3=43	T_4=91
Pressure kPa	P_1= 530	P_2= 1648	P_3= 1586	P_4= 627.4
Density kg/m^3	ρ_1=20	ρ_2=85	ρ_3=1070	ρ_4=100
Entropy kJ/kg.k	S_1=1.78	S_2=1.77	S_3=1.23	S_4=1.25
Enthalpy kJ/kg	H_1=419	h_2=450	h_3=260	h_4=260

4. Results and Discussion

The results of calculations for power consumption, mass flow rate, cooling capacity, refrigeration effect and COP and volumetric efficiency η_v for Run A are shown in Table 9. for power consumption of small water pump is very low comparing with the power consumption of compressor which its value 52W, and this value remain constant in two sets. The results show actual power consumption of split unit air conditioning system P_{cons} decrease about 18% and cooling capacity Q_c increase 19% and refrigerant effect q_c increase 21%. The COP which is the most important parameter increase about 48%. Table 9 shows the η_v increased by 4%, this percent is not high because the compressor used is itself so same theoretical displacement, the variable parameter is actual volume V_3 and the difference in η_v magnitude is very small between two sates i.e. with and without evaporative cooling. Thus indicates that by employing evaporative cooler not only power consumption decreases but also cooling capacity also increase.

Table 10 shows the results of calculation for Run B. Power consumption W_c decrease about 16% and COP increase about 73% which show considerable savings.

Table 9

Experimental results in Run A.

Parameter	*Unit*	*Without Evap.*	*Evaporation*	*Variation*
P_{cons}	W	2210.2	1873.6	-18%
$\dot{m}$	Kg/s	0.03425	0.035	+%2
Q_c	W	4521	5635	+19%
Cop	-	2.09	3.09	+%48
q_c	kJ/kg	132	161	+21%
W_c	W	2160.9	1820	-16%
η_v	-	93%	97%	+4%

Table 10
Experimental results in Run B.

Parameter	*Unit*	*Without Evap.*	*Evaporation*	*Variation*
P_{cons}	W	2527	2131	-%18
$\dot{m}$	Kg/s	0.05156	0.067	+23%
Q_c	W	7321.52	10653	+%31
Cop	-	2.95	5.12	+73%
q_c	kJ/kg	142	159	+11%
W_c	W	2476.8	2077	-16%
η_v	-	93%	96%	+3%

5. Conclusions

Due to the extreme ambient conditions in Iraq (represented by the high dry bulb temperature) the performance of small size Air conditioning systems like Air conditioner or split type Air conditioning reduced and electrical consumption increasing so we used the evaporative cooling to improve that evaporative cooling to get high performance we must introduced a novel design. This design is very simple and it could easily applied on existing air conditioner of window type or split unit type.

The experimental results show the confident performance of split unit with and without media pad evaporative cooling on the condenser cooling effect and cooling capacity are increased. But the electrical power consumption is decrease so we recommended for using the indirect evaporative condenser in very hot weather conductions in stead of conventional air condenser to save electric power and increase cooling capacity.

For economical analysis based on local prices shows the energy saving can pay for the cost associate with retrofitting the condenser in less than 1 year.

Nomenclatures

Cop: Coefficient of performance
η_v **: Volumetric efficiency**
h: Enthalpy, kJ/kg
I: Electric current, A
$\dot{m}$ **: Refrigerant mass flow rates, kg/s**
P: Pressure, kPa
P_{cons}**: Power consumption, W**
Q_c **: Cooling capacity, W**
q_c **: Cooling effect, kJ/kg**
ρ **: :Density, kg/m^3**
s: Entropy, kJ/kg.k
T: Temperature, C^o
V: Electric voltage, V
υ **: Specific volume, m^3/kg**
W_c**: Compressor work, W**

Subscripts

dis: discharge pressure
suc: suction pressure

References:

[1] M.M. Awad, H.M. Mustafa, G.I.Sultan,A.Elbooz, A. M. K. Elghonemy,2007, "Performance Enhancement of Air –Cooled Condensers", Acta polytechnic Hungarica, Vol.1, No.2, pp.125-142.
[2] Chow, T.T, Lin, Z., and Yang, X.Y, 2002," Placement of Condensing Unit of Split-Type Air-Conditioners at Low-Rise Residences", Applied Thermal Engineering, Vol. 22, pp.143-153.
[3] Y. Hwang, R. Rademacher, W. Kopko, 2001,"An Experimental Evaluation of a Residential-Sized Evaporatively Cooled Condenser", International Journal of Refrigeration, Vol. 24, pp 238-249.

[4] S.S. Hu, B.J. Huang, 2005,"Study of High Efficiency Residential Split Water -Cooled", Applied Thermal Engineering, Vol. 25, pp 1599-1613.

[5] Chainarong Chaktranond, and Peachrakha Doungsong, 2010, " An Experimental Evaluation of Energy Saving in a Split –Type Air Conditioner with Evaporative Cooling Systems" , International Transaction of Engineering Management & Applied Sciences Technology, , Vol.1, pp. 9-18.

[6] D.Y. Goswami, G.D.Mathur,S.M. Kulkarni, 1993, "Experimental Investigation of Performance of a Residential Air Conditioning System with an Evaporatively Cooled condenser", Journal of Solar Energy Engineering , Vol.115, pp. 206-211.

[7] ASHRAE Fundamental, 1997.

[8] Shan K. Wang, 2000," Handbook of Air Conditioning And refrigeration", McGraw-Hill, New York.

[9] ASHRAE System and Equipment Handbook, 2000.