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Enhancement of the Performance Characteristics for Air-Conditioning System by Using Direct Evaporative Cooling in Hot Climates

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Abstract

This paper presents an experimental study to enhance the performance of a small air condition (A/C) system by mean of direct evaporative cooling method. A setup of cooling system is designed to simulate extremely hot weather where the dry bulb temperature (DBT) reaches the vicinity of 55 ◦C which represents the highest possible weather temperature that was recorded during summer. The proposed design utilizing an evaporative cooling cycle where the air flows over wet pads before it goes through the condenser. Four different parameters are considered to be studied, namely coefficient of performance (COP), energy saving, cooling capacity and the compressor auto-shut down in very high weather temperature. The results showed significant enhancement to the entire A/C system performance where the refrigeration capacity is increased in the range of 5% to 7.5% and there is 0.12A to 0.16A electrical current reduction for each temperature degree reduction. Moreover, and the compressor continued working even with a voltage drop of 16% (185 V instead of 220 V) which can help overcoming a serious problem that middle east countries (such Iraq) suffer during summer.

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Keywords: Direct Evaporative Cooling, Hot Climate, Air-Conditioning System, Energy saving.

1. Introduction

Enhancing the performance of cooling systems has been a hot topic during the last decades. Several investigations were presented by many different researchers to find alternative techniques for buildings air conditioning methods. Yet, the currently available air conditioning systems are efficient and reliable in term of operating and fulfilling the need of air conditioning. However, the challenge of high energy consumption in such air-conditioning systems stills under ongoing studies. Especially there is a continuous demand for the energy worldwide which requires serious

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solutions to avoid energy lack in the near future. Nowadays, about thirty percent of the total world energy goes to the energy consumption in air-conditioning applications [4]. Furthermore, the using of A/C and mechanical ventilation systems in the small building still expensive since it costs 65% of energy consumption bills [1,2]. Worldwide, experimental and theoretical studies are conducted contentiously to present efficacious approaches to reduce the energy consumption by enhancing the performance of vapour compression systems [8]. Ebrahim Hajidavalloo [3] used pads to design a direct evaporative cooling system for a condenser to enhance cooling capacity and energy saving. Another theoretical study is presented by M.M. Nasr and M. S. Hassan [5], and M.R. Islam, et al. [4] to enhance the performance of a small size refrigeration system by direct evaporative cooling method. The performance of a split unit A/C system is also considered to be studied experimentally Y.H. Yau and H.L. Pean [9]. Tianwei, et al. [6] presented an experimental study for the comparison between the air cooling in conventional and evaporation air cooling condenser. Nikhil Sharma1 and Jujhar Singh [7] implemented the wastewater of water-cooler in evaporative cooling in window A/C system to reduce the power consumption and humidity in very hot weather condition. The power consumption can be improved by using pads with different thicknesses to perform pre-cooling effect in A/C system [10]. For more details about using of evaporative cooling, reader can refer to [11]. It is common in vapor compression system that the manufacturer designs a shutdown switch (overload sensor) within the compressor which shuts down the compressor when the voltage drops below certain limit. When the weather temperature goes higher than specific threshold the entire system shuts down automatically. In the Middle East countries such as Iraq, this problem has been serious challenging since the temperature is extreme during summer and reaches up to 52 ◦C [12]. Thus, during severe hot weather period (July-August) the voltage drops below the threshold (200 V) in the National Electric Power Network, and the A/C systems become useless which exacerbates the people suffering. This work presents an enhancement to energy saving, COP, cooling capacity and minimum operation voltage limit.

2. Experimental Rig Setup and Uncertainty

The experimental tests are performed on widow type A/C system, which operates using R22 as a refrigerant, and an evaporative cooling system is added as an extension to the A/C system. The entire system is designed to be controllable in terms of various weather conditions. The experimental a 7 kW (2 ton of refrigeration) cooling capacity refrigeration unit is used in this work, where the dimensions of the evaporator are 48 cm × 61 cm × 2 rows. The implemented condenser has a capacity of 11 kW and its dimensions are 63.5 cm × 76.2 cm × 2 rows, both the evaporator and condenser have the same number of fins per centmeter (3.15 FPCM). For each run the air velocity stays the same through the condenser and evaporator to simulate the real operation of the A/C. We considered three different air velocities namely (1, 2 and 3 m/s) [13], [6] and [3]. The pads are kept saturated with water by mean of water distributing system consists of tank, water pump, and distributing as shown in Fig. (1). in each input and output for the four components (compressor, condenser, expansion valve, and evaporator), we installed pressure gauges and A T-type thermocouples probes and the data is collected by mean of digital data logger, and the air velocity is recorded by digital anemometer. A rotameter is used to measure the water flow through the pads. Also, the power, voltage, and current are measured by mean of a digital AC power meter. Each experiment run takes 90 minutes period as follows; first, choose a predetermined temperature, fan speed, and relative humidity by switching on heater, humidifier, and fan for 30 minute to ensure the simulation of weather condition. Second, the A/C system runs on for another 30 minutes to achieve steady state condition. Finally, the data (relative humidity, temperature, current, voltage and pressure) will be recorded continuously for another 30 minutes. For all elements, Taylor method [14] is used to combine uncertainties. The main uncertainties in this work are represented in refrigerant mass flow rate, refrigeration effect, cooling capacity and COP, are in the range (1.25 - 3.2) depending on the test conditions. The error can be obtained by using the Root-Sum-Squares (RSS) uncertainty method [14]

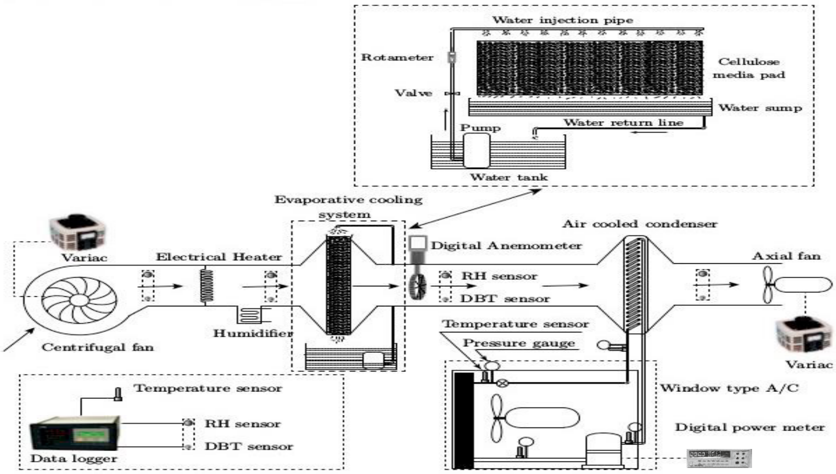

Figure 1 Illustration of experimental rig.

3. R*e*sult and discussion

To study the performance of condenser with the aid of evaporative cooling, there are many parameters should be considered, namely the air velocity, relative humidity and DBT. The experiment runs are identical for two different simulated cases to study the performance of A/C system (with and without evaporative cooling). To simulate the real conditions of various weather environments, we selected wide ranges of steady state RH and DBT, however only some values are illustrated on the psychometric chart with 10% RH, the DBTs are chosen to be 45◦C, 50◦C and 55◦C since actual hot weather in Iraq during summer starts from 45◦C and ends high up to 55◦C. Figure(2) shows the energy variation in the A/C system with and without evaporative cooling, where dashed-line represents the phase change in the refrigerant, where the amount of heat in the air is increases since the DBT is increases sensibly (no change in moisture content) when the air flows across the condenser. The pads in the evaporative cooling system work as humidifier when the air passes through it. Contrarily, the DBT decreases which causes precooling to the air that passes through the saturated pads, and this process is adiabatic and plotted as inclined line. The air leaves the pads cooler and humid and since when it passes through the condenser a sensible heat exchange occurs, and the process is represented by horizontal lines. It has been scientifically proven before that the amount of heat transfer is proportional to air velocity. Hence, we investigate low (1 m/s), medium (2 m/s), and high (3 m/s) air velocities. The results show that the air velocity affects the COP and energy saving significantly, where the pressure drop decreases at low air velocity and hence the efficiency of evaporative cooling increases. This fact is mathematically proven by the expression (/ 1/2V 2))[13] which is clearly illustrated in Fig.(4-a). Also, one can see from Fig.(3) that the most efficient air velocity is(1 m/s). Consequently, the fan consumes more power when the pressure drops and this result is shown in Fig.(4-b).

In the experimental procedure, three different sets of data are considered, namely runs (A, B and C) which are detailed in table (1) which represent the maximum possible effect of evaporative cooling on the A/C system and it is shown in Fig. (5) on the P-h chart. One can observe from Fig. (5) That the condenser pressure is reduced within the range of (24.7%-41.7%). One the other hand, the low pressure (evaporator pressure) is reduced in the range of (21.4%- 11%). it implies that the compression ratio is reduced which means that the compressor will need less energy, and that is where the energy is saved within the range (22.45% - 33.96%). Also, it can be observed from Fig.(5) that a sub cool phenomenon occurs in the condenser (supported by evaporative cooling) and this implies that the refrigeration capacity will be increased and it is observed within the range of 5% to 7.5% for each ton of refrigeration.

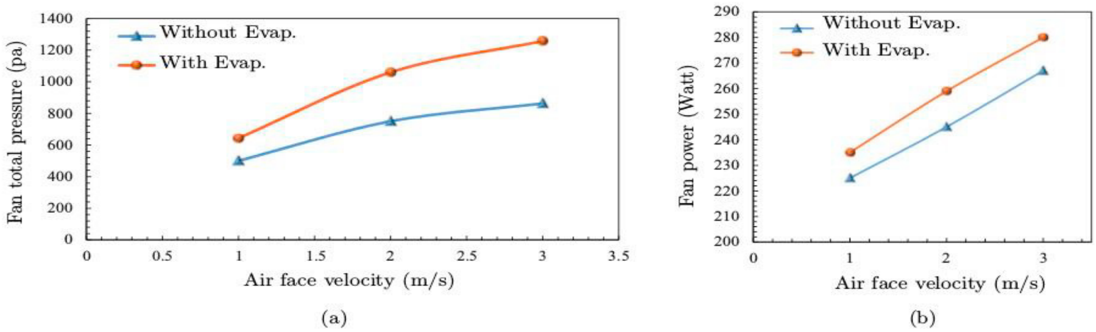

Figure 3 (a) Pressure drop variation under the effect of evaporative cooling. (b) Fan power under the effect of evaporative cooling aid.

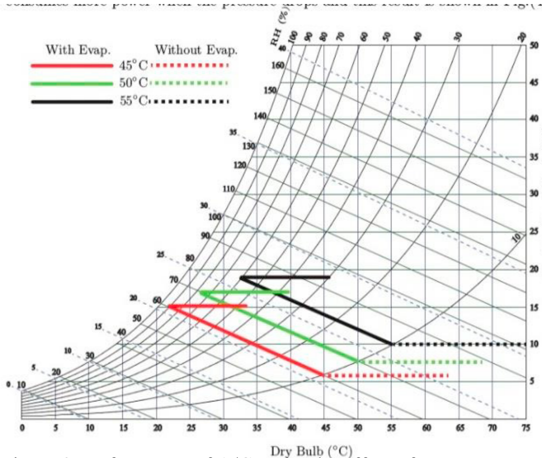

Figure 3 Performance of A/C under the effect of DBT.

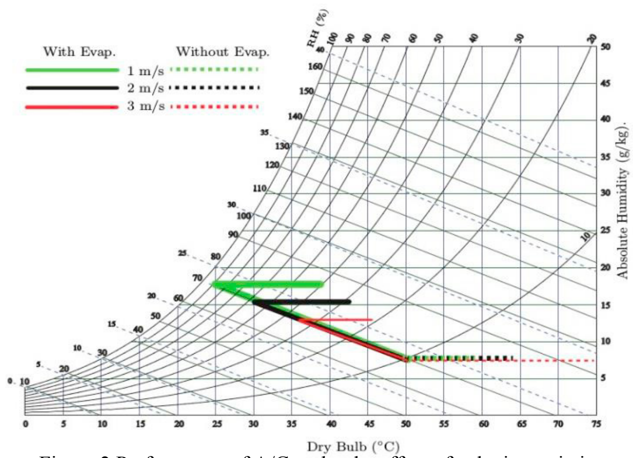

Figure 2 Performance of A/C under the effect of velocity variation.

Table 1 Comparison between three different with and without presence of evaporative cooling.

Parameters	Unit	Run A		Run B		Run C	
		Without Evap	With Evap	Without Evap	With Evap	Without Evap	With Evap
Ambient DBT	ºC	45	45	50	50	55	55
Ambient WBT	ºC	21.3	21.3	23.9	23.9	26.5	26.5
Compressor exit temperature (T_2)	ºC	109	84	112	83.4	119	84.8
Condenser exit temperature (T_3)	ºC	58	40	62	43	71	46
Capillary tube exit temperature (T_4)	ºC	0	-6	2.5	-1	4.5	2
Evaporator exit temperature (T_1)	ºC	9	0	11.5	3	15	5.2
Condenser air exit temperature	ºC	59	40	62	43	68	46.2
Electric current	A	12	9.8	13.1	10.1	14.2	10.6
Compressor exit pressure (P_2)	Bar	24.75	19.85	27.21	20.06	30.6	21.6
Condenser exit pressure (P_3)	Bar	24.64	19.431	27.98	19.912	30.4	21.41
Capillary exit pressure (P_4)	Bar	4.98	4.1	5.468	4.864	5.821	5.2
Evaporator exit pressure (P_1)	bar	4.891	4.01	5.294	4.751	5.672	5.11
Compression ratio	-	5.06	4.95	5.21	4.223	5.4	4.227
Water evaporation rate	l/min	-	0.2	-	0.3	-	0.41
Water circulation rat	l/min	-	4.5	-	4.5	-	4.5

The refrigerant mass flow, refrigerant, cooling capacity and COP are calculated using equation in [13]. The work used in compressor is obtained directly from digital wattmeter as shown Fig. (1). Data in table (2) shows the refrigerant effect is increased in range of (10.2%-15.87%), refrigerant mass flow rate is increased in the range of (12.5%-10.95%) cooling capacity also is increased in range of (27.12%-33.4%). Whereas COP in increased in range of (17.8%- 33.24%). The influence of inlet RH on the energy saving with using of evaporative cooling is shown in Fig. (6). It is clear from the figure that the energy usage is reduced when the inlet RH is increased and this implies that the precool and energy reduction capability for the A/C system with support of evaporative cooling is decreased

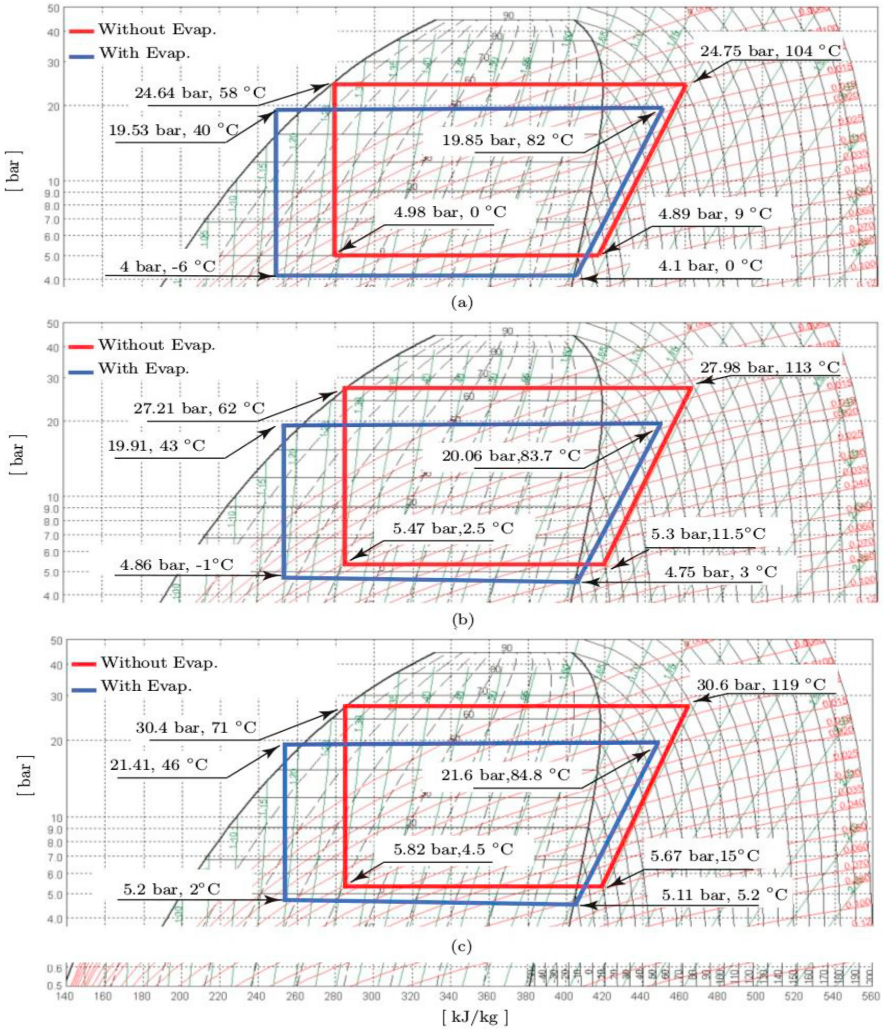

Figure 4 Cycles with and without evaporative cooling (a) The P-h charts for run A, (b) The P-h charts for run B, (c) for run C

Generally, the effect of evaporative cooling decreases when the RH is increases, since smaller moisture content change to achieve saturation condition.

Table 2 Comparison of Specification for AC with and without evaporative cooling.

Parameters	Unit	Run A		Run B		Run C	
		Without Evap	With Evap	Without Evap	With Evap	Without Evap	With Evap
Power saving	-	22.45%		29.703%		33.96%	
Refrigeration effect	kJ/kg	142	158	130	149	122	145
Refrigerant mass flow rate	kg/s	0.0561	0.0641	0.0589	0.067	0.061	0.0685
Cooling capacity	kw	7.9662	10.127	7.657	9.983	7.445	9.932
Compressor work	kJ/kg	47	42	48	43	53	43
Coefficient of Performance, COP	-	3.0212	3.6744	2.7085	3.512	2.303	3.45
% improvement of COP	-	17.8%		22.87%		33.24%	

4. Conclusion

This work presents a study to use the direct evaporative cooling to enhance the performance of A/C system. The design consists of window type A/C system that is supported by an evaporative cooling system and both work as one compact unit and the proposed design is able to simulate a wide range of weather conditions including severe hot weather temperature and relative humidity. It is shown from the experimental results that by using the evaporative cooling aid, the performance of the A/C system can be improved significantly in term of COP, cooling capacity, and energy saving. The evaporative cooling system consists of evaporator made of sawdust and compact together to form a pad, where the pad is to be saturated continuously with water by mean of water cycling system designed for this purpose. When the air flows through the pad, it become humid and its DBT decreases, hence the air is precooled before it flows through the condenser. The liquid mass flow rate increases in the condenser because of the flow of precooled air. As a result, the compression ratio decreases which implies a significant improvement in the performance of the compressor, where the electric demand is reduced within a range of (0.12-0.16 A) per 1 ◦C reduction. Also, the refrigeration capacity is improved in the range of (5-7.5 %). Furthermore, the results show that the evaporative cooling aid helps to avoid the problem of auto shutdown in

A/C system during severe hot weather especially when the applied voltage drops below allowed threshold. The present model operates even when the voltage drops to 185 V, and hence, the challenge of A/C shut down during severe hot weather is overcome in Iraq. This work is extendable and more details will be included in the journal version of the work where a heat exchanger is implemented along with the evaporative system.

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